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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 126

EQUIPMENT FOR OBTAINING PAVEMENT CONDITION AND TRAFFIC LOADING DATA

TRANSPORTATION RESEARCH BOARD
National Research Council

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

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C.
SEPTEMBER 1986

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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NCHRP SYNTHESIS 126

Project 20-5 FY 1983 (Topic 15-04)
ISSN 0547-5570
ISBN 0-309-04012-4
Library of Congress Catalog Card No. 86-50378

Price: $11.20

Subject Areas
Pavement Design and Performance

Mode
Highway Transportation

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

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Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to pavement designers, maintenance engineers, planners, and others concerned with measuring the condition of existing pavements for the purpose of planning maintenance, rehabilitation, or reconstruction. Information is presented on the types of equipment being used to obtain data on structural capacity, surface distress, friction, roughness, and traffic loading.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Many highway agencies are using pavement management systems for scheduling rehabilitation and maintenance activities. These systems require data on pavement condition and traffic loading. This report of the Transportation Research Board describes the types of equipment being used by state highway agencies to obtain these data.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Damian J. Kulash, Assistant Director for Special Projects. The principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers. This synthesis was edited by Anne S. Brennan.

Special appreciation is expressed to Jon A. Epps, Department of Civil Engineering, University of Nevada, and Carl L. Monismith, Department of Civil Engineering, University of California, Berkeley, who were responsible for the collection of the data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Karl H. Dunn, Research Engineer, Wisconsin Department of Transportation; Kenneth McGhee, Senior Research Scientist, Virginia Highway and Transportation Research Council; G. C. Page, Bituminous Materials and Pavement Evaluation Engineer, Florida Department of Transportation; Rolands L. Rizenbergs, Associate Assistant State Highway Engineer, Kentucky Department of Highways; and Liaison Members Frank Botelho, Highway Engineer, and Roger Petzold, Highway Engineer, Federal Highway Administration.

George W. Ring, Engineer of Design, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

EQUIPMENT FOR OBTAINING PAVEMENT CONDITION AND TRAFFIC LOADING DATA

SUMMARY

This synthesis identifies equipment that is used to provide data to measure structural capacity, surface distress, friction, roughness, and traffic loading. Current state practices, costs, maintenance requirements, advantages and disadvantages, and new equipment development are discussed.

Pavement management is a systematic procedure for scheduling maintenance and rehabilitation to optimize benefits and to minimize costs. The measure of structural capacity is made to obtain an estimate of the remaining life for the pavement and to provide information to use in the design of rehabilitation measures. Equipment currently in use to evaluate structural capacity generally use a measure of surface deflection under a slow-moving, vibrating, or falling load.

The Benkelman beam is the most common equipment used to measure the response of pavement to a slow-moving load. The Dynaflect and Road Rater have been used extensively for steady state vibratory loading. The falling-weight deflectometer develops an impulse load by dropping a mass from a specific height to the pavement.

Pavement distress, an indicator of structural performance, is generally considered by engineers to be at least as important as functional performance. Such distress is broadly associated with environment, traffic, or materials. Techniques for measuring physical distress and types of distress catalogued vary by agency and depend on the purpose for which the information is collected.

Pavement surface friction characteristics are measured mostly using either the locked-wheel-trailer procedure or the yaw mode procedure.

Ride quality is generally related to the roughness of the pavement and is measured by either response-type equipment or profilometers.

Equipment for collecting traffic volume and traffic weights are portable counters, fixed counters, weigh-in-motion devices, portable scales, and permanent weigh stations. Portable and fixed counters can give the number and types of vehicles. Vehicle weights and axle loads are obtained from the weigh-in-motion devices, portable scales, and permanent weigh stations.

CHAPTER ONE

INTRODUCTION

BACKGROUND

At every level of government, funds that have been earmarked for pavements must be used as effectively as possible. One method to accomplish this is through the use of pavement management (*1, 2*).

Considerable effort is now under way at the state level to implement working pavement management systems and a number of states are already effectively using pavement management techniques for scheduling maintenance and rehabilitation activities. Many local governments also have efforts under way to implement pavement management activities. Although these agencies have developed a diverse range of systems, all systems have several key elements in common. The collection of pavement condition and traffic loading data is a common key element.

The largest cost associated with operating pavement management systems is that for collecting pavement condition and traffic loading data. At present, state and local governmental agencies use a wide variety of equipment and techniques to collect this information. New equipment is being developed that will collect these data in a shorter period of time and with greater safety of operation.

This synthesis identifies equipment associated with the collection of structural capacity, surface distress, friction, roughness, and traffic loading data. Current practices, costs, and maintenance requirements are presented. Advantages and disadvantages of particular types of equipment are also presented and new equipment developments are briefly discussed.

This synthesis was prepared with information obtained from the literature and through the use of a survey (Appendix A). The survey was circulated in June 1983 to the states, Canadian provinces, and selected countries outside of North America to supplement information contained in the published literature and obtained from manufacturers. Forty-four states responded to the questionnaire. A summary of the data obtained from the responses is given in Table 1. More detailed summaries are contained in Appendixes C through G. References obtained in response to the questionnaire (noted in Table 1) are listed in Appendix B. Individual states can be contacted for detailed information. Appendix H gives names of manufacturers of the various types of equipment.

This report covers only the equipment used to obtain data on pavement condition and traffic loading. More information on how and when agencies collect the data and on how they use the data can be found in Synthesis 76 (*3*) and in other sources.

PAVEMENT MANAGEMENT

Through the use of a pavement management system, administrators and engineers have the opportunity to effectively allocate resources to maintain the network of streets and highways. A pavement management system, simply stated, is a systematic procedure for scheduling maintenance and rehabilitation activities to optimize benefits to the users of the facilities and to minimize costs to the agency responsible for the system. (In its broadest sense, pavement management includes the consideration of new designs as well as maintenance and rehabilitation activities.)

Pavement *maintenance* is defined as those processes, both preventive and corrective, that do not involve major alterations in the existing pavement structure. *Rehabilitation* includes reconstruction, overlays, recycling (hot or cold), and their combinations, accomplished either to restore or to improve serviceability and often to increase the structural capabilities of the pavement. A general framework for such activities is shown in Figure 1.

Pavement management activities are generally characterized at two administrative levels termed the network and project levels (Figure 2) (*1*). At the network level, decisions are made primarily for large groups of projects or an entire highway network such as a state highway system. The project level is concerned with more specific technical management decisions for individual projects for which additional engineering information is available.

> At either level, the system should permit:
>
> 1. Definition of projects in need of maintenance and rehabilitation,
> 2. Identification of type of maintenance and/or rehabilitation required, and
> 3. Identification of type and timing of future maintenance and rehabilitation to minimize life-cycle costs (or maximize benefits).
>
> With a properly functioning network-level system, estimates of the costs to bring the network to, and maintain it at, some desired level of serviceability are possible. Alternatively, in the face of budget constraints, a measure of the resulting serviceability levels associated with specific budget levels can be predicted.
>
> It should be emphasized that the network- and project-level systems are interrelated and provide feedback to each other when properly functioning. For example, a properly functioning project-level system ensures credible output at the network level (*1*).

Essentially, the network-level management system identifies groups of projects that are anticipated to require some expend-

TABLE 1

EQUIPMENT FOR OBTAINING PAVEMENT MANAGEMENT DATA (1983)

Public Agency	Structural Capacity	Surface Distress	Friction	Roughness	Traffic Volume and Weight	Other	Reference
Alabama	Soiltest Model 300 Benkelman Beam	Developing Visual Condition Form	Soiltest Locked Wheel Skid Trailer	Modified Soiltest BPR Type Roughometer	Portable and Fixed Weigh-In-Motion Scales		
Alaska	Dynatest Model 8600 Falling Weight Deflectometer	Visual Condition Form		Rainhart Trailer-Mounted Mays Meter	Portable and Fixed Counters, Permanent Scales		
Arizona	SIE Dynaflect Phoenix/Dynaflect Falling Weight Deflectometer		Bison/ML Aviation Mu Meter	Rainhart Mays Meter	Portable and Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		
Arkansas	SIE Dynaflect	Visual Condition Form	Bradbar & U. of Arkansas Locked Wheel Skid Trailer	Rainhart Mays Meter, Station Wagon & Tow Trailer	Portable and Fixed Counters, Portable Scales		
California	SIE Model 1000-8A Dynaflect	Visual Condition Form	California Portable K.J. Law, Model 926	California Profilograph			B2
Connecticut	Benkelman Beam	Techwest Photolog System	British Pendulum K.J. Law Model 1270 Locked-Wheel Skid Trailer	Techwest Photolog System, Soiltest Hi-Low Detectors			B3, B4, B5
Delaware			Photolog System		Portable and Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		B6
Florida	Grosource Inc. Dynaflect, Soiltest Benkelman Beam, Dynaflect, Falling Weight Deflectometer	Visual Condition Form	K.J. Law, Model 1270 Locked-Wheel Skid Trailer	Rainhart Mays Meter, Trailer Mounted; Chloe Profilometer	Portable and Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		B7
Georgia	SIE Dynaflect, Benkelman Beam	Visual Condition Form	Soiltest Locked Wheel Skid Trailer	Rainhart Mays Meter, Trailer Mounted; Rainhart Profilometers	Portable and Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Stations	Traffic Counts by Time Lapse Video Systems	B8, B9
Hawaii	Benkelman Beam	Visual Condition Survey	K.J. Law Locked Wheel Skid Trailer	Cox & Sons Ride Meter	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales		
Idaho	SIE Model 1000-8A Dynaflect, Soiltest Benkelman Beam	Visual Condition Survey	Soiltest ML 350 Locked Wheel Skid Trailer, Aviation MK3 Mu Meter	Cox & Sons Ultrasonic Roadmeter	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		

TABLE 1

EQUIPMENT FOR OBTAINING PAVEMENT MANAGEMENT DATA (1983) (*Continued*)

Public Agency	Structural Capacity	Surface Distress	Friction	Roughness	Traffic Volume and Weight	Other	Reference
Illinois	Benkelman Beam, Foundation Mechanics Model	SIE Inc. Delam-tec, Visual Condition Form	Soiltest Locked Wheel Skid Trailer	Soiltest BPR-Type Roadmeter	Portable Counters, Fixed Counters, Portable Scales, Permanent Weigh Station		B10, B11, B12, B13
Indiana	SIE Dynaflect	Visual Condition Survey	FMC Locked Wheel Skid Trailer	Cox & Sons Ultra-sonic Roadmeter			B14
Iowa	Foundation Mechanics Model 400 Road Rater	Visual Condition Survey	K.J. Law Model 2400 Locked Wheel Skid	Iowa Johannsen-Kirk Roadmeter	Portable Counters, Fixed Counters, Portable Scales		B15, B16, B17, B18, B19
Kansas	SIE Dynaflect	International Cybernetics PCR 2000 Pavement Con-dition Recorder, Techwest Photolog	K.J. Law Model 1270 Locked Wheel Skid Trailer	Rainhart Mays Ride Meter	Portable Counters, Fixed Counters, Portable Scales		
Kentucky	Foundation Mechanics Model 400 Road Rater, Soiltest Benkelman Beam	Visual Condition Form	K.J. Law Locked Wheel Skid Trailer	Rainhart Mays Meter			B20, B21, B22, B23
Louisiana	SIE Dynaflect	Flight Research Photologger	K.J. Law Locked Wheel Skid Trailer, ML Aviation Mu Meter	Rainhart Mays Meter, Rainhart Profilograph			B24
Maine					Weigh In Motion		B25
Maryland	Foundation Mechanics Model 400/B Road Rater	Visual Condition Survey	K.J. Law Locked Wheel Skid Trailer	Rainhart Mays Meter	Portable Counters, Fixed Counters		B26
Mass.			K.J. Law Locked Wheel Skid Trailer	Rainhart Station Wagon-Mounted Mays Meter			
Michigan	Soil Test Benkelman Beam	Visual Condition Form, Photo Equip-ment	K.J. Law Locked Wheel Skid Trailer, British Portable Tester	Michigan DOT Profilometer	Portable Counters, Fixed Counters, Por-table Scales, Permanent Weigh Station		
Minnesota	Foundation Mechanics Model 2000 Road Rater		K.J. Law Model 1270 Locked Wheel Skid Trailer	Minn DOT PCA Meter	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales		B20, B27, B29, B30
Missouri	Soiltest Benkelman Beam	Missouri DOT Pave-ment Edge Strain Gauge	K.J. Law Model 1270 Locked Wheel Skid Trailer	Chloe Profilo-meter, BPR Roughometer	Portable Counters, Fixed Counters, Portable Scales, Permanent Weigh Station		

TABLE 1

EQUIPMENT FOR OBTAINING PAVEMENT MANAGEMENT DATA (1983) (*Continued*)

Public Agency	Structural Capacity	Surface Distress	Friction	Roughness	Traffic Volume and Weight	Other	Reference
Nebraska	Dynaflect	Visual Condition Form, Rut Depth	K.J. Law Locked Wheel Skid Trailer	Soiltest Wisconsin Type Road-meter	Portable Counters, Fixed Counters, Portable Scales, Permanent Weigh Station		
Nevada	SIE Dynaflect	Visual Condition Form, Photo Equipment	K.J. Law Locked Wheel Skid Trailer, Cox & Sons, Locked Wheel Skid Trailer	Cox & Sons Ride-meter (Mechanical) (Ultrasonic)			B31, B32, B33
New Hampshire			Maine DOT Locked Wheel Skid Trailer	Rainhart Mays Meter	Fixed Counters, Permanent Weigh Station		
New Jersey	Soiltest Benkelman Beam	Visual Condition Form	Stevens Institute Locked Wheel Skid Trailer	Rainhart Mays Meter, Auto Mounted	Portable Counters, Fixed Counters, Portable Scales		
New York	N.Y. DOT Benkelman Beam	Visual Condition Survey, Instrumentation Marketing Corp., Photolog Camera System	N.Y. DOT Locked Wheel Skid Trailer	Automated Pavement Response Roughness Test System	Portable Counters, Fixed Counters, Portable Scales		B34, B35, B36, B37, B38, B39
Ohio		Visual Condition Survey, Techwest Photologger, IMC Photologger	K.J. Law Model 1270 Locked Wheel Skid Tester	Rainhart Mays Meter, Car-Mounted; K.J. Law Model 6900 Surface Dynamics Profilometer	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales		B40
Oklahoma	Soiltest Benkelman Beam	Visual Condition Survey	Oklahoma DOT Locked Wheel Skid Trailer	Rainhart Mays Meter	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		B41
Oregon	Soiltest Model H-350 Benkelman Beam, SIE Model DDSCE Dynaflect		K.J. Law Model 1270 Locked Wheel Skid Trailer	Oregon DOT Road-meter (PCA Type)	Portable Counters, Fixed Counters, Portable Scales, Permanent Weigh Station		
Penn.	Foundation Mechanics RR 400 Road Rater	Visual Condition Survey	K.J. Law Locked Wheel Skid Trailer	Rainhart DMC Transwave Corp. Mays Meter	Portable Counters, Fixed Counters, Portable Scales		B42, B43, B44
Rhode Island	Soiltest Benkelman Beam		K.J. Law Locked Wheel Trailer		Portable Counters, Fixed Counters		
South Carolina	Soiltest Benkelman Beam		K.J. Law Models 1270 & 1275A Locked Wheel Skid Trailer	Rainhart Mays Meter	Portable Counters, Fixed Counters, Portable Scales		

TABLE 1

EQUIPMENT FOR OBTAINING PAVEMENT MANAGEMENT DATA (1983) (*Continued*)

Public Agency	Structural Capacity	Surface Distress	Friction	Roughness	Traffic Volume and Weight	Other	Reference
South Dakota	SIE Dynaflect	IMC Photolog	K.J. Law Model 1270 Locked Wheel Skid Trailer	S. Dakota Profilometer	Portable Counters, Fixed Counters, Weigh-In-Motion, Portable Scales		B45, B46, B47
Tenn.	Dynaflect Falling Weight Deflectometer	Visual Condition Form	K.J. Law Locked Wheel Skid Trailer	Rainhart Mays Meter	Portable Counters, Fixed Counters, Portable Scales, Permanent Weigh Station		
Texas	Soiltest, Benkelman Beam, SIE Model 1000-8A Dynaflect	Visual Condition Form, Photo Equipment	Texas DOT Locked Wheel Skid Trailer	Rainhart Mays Meter, K.J. Law Surface Dynamics Profilometer	Portable Counters, Fixed Counters, Weigh-In-Motion Scales, Permanent Weigh Station		B48, B49, B50, B51, B52, B53, B54
Utah	Dynaflect	Visual Condition Form	M.L. Aviation Mu Meter	Cox Ultrasonic Road Meter	Portable Counters, Fixed Counters, Portable Scales, Permanent Weigh Station		B55
Vermont				Rainhart Mays Meter	Portable Counters, Fixed Counters, Portable Scales, Permanent Weigh Station		
Virginia	Lane Wells Dynaflect	Visual Condition Form	K.J. Law Locked Wheel Skid Trailer	Rainhart Mays Meter	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		B56
Washington	Dynaflect Model 8000, Falling Weight Deflectometer	Visual Condition Form	K.J. Law Model 1270 Locked Wheel Skid Trailer	Cox Model 8000 Ultrasonic Roadmeter	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		
West Virginia	SIE Model 1000-8A Dynaflect		K.J. Law Locked Wheel Skid Trailer	Rainhart Mays Meter Car Mounted K.J. Law G.M. Profilometer	Portable Counters, Fixed Counters, Weigh-In-Motion and Portable Scales, Permanent Weigh Station		
Wisconsin	Soiltest Benkelman Beam	Techwest Photolog	Soiltest Locked Wheel Skid Trailer	PCA Meter	Weigh-In-Motion Scales		B56
Wyoming	SIE Dynaflect		K.J. Law Model 1270 Locked Wheel Skid Trailer	Rainhart Mays Meter			

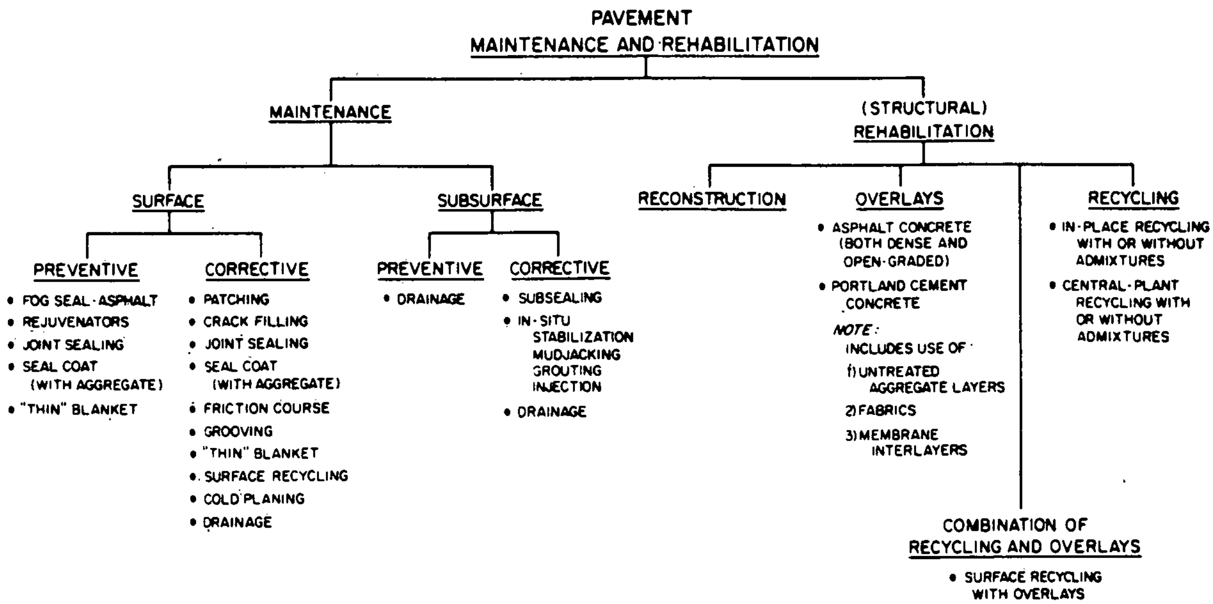


FIGURE 1 Pavement maintenance and rehabilitation considerations (*1*).

iture of funds in any given time period and should provide a target activity and cost estimate. The project-level management system should verify the accuracy of the data obtained and test the recommendations from the network to determine if more cost-effective or possibly more reliable actions can be taken that will meet the overall performance goals without significantly increasing budget requirements. The complete management system should include the optimization feature necessary to achieve the greatest benefit for the least cost.

Network-Level Management System

The essential elements of a network-level management (or network optimization) system and the steps in making decisions at the network level are shown in Figure 3.

A necessary part of the network system, and the project system as well, is the data bank of information and its associated management activities, termed herein the data management system.

The type of information needed for a network-level system includes (*1*):

1. Ride quality [roughness, present serviceability index (PSI), ride comfort index, etc.];
2. Physical distress (type, extent, severity);
3. Safety (primarily friction characteristics); and
4. Traffic volume and weight.

These data are obtained during the network monitoring phase.

Project-Level Management System

A primary objective of the project-level management system is to determine the optimal (the most cost-effective) rehabilitation actions for a given project over a designated analysis period. The output of the network-level system provides target maintenance and rehabilitation actions and the associated costs for pavements in different conditions. However, more detailed and site-specific information can be used in the project-level system to investigate alternative actions that may be more cost-effective for a given project.

Figure 4 illustrates schematically the process at the project level. An additional requirement at this level (in the Diagnostic Investigators phase) is the measurement of structural capacity;

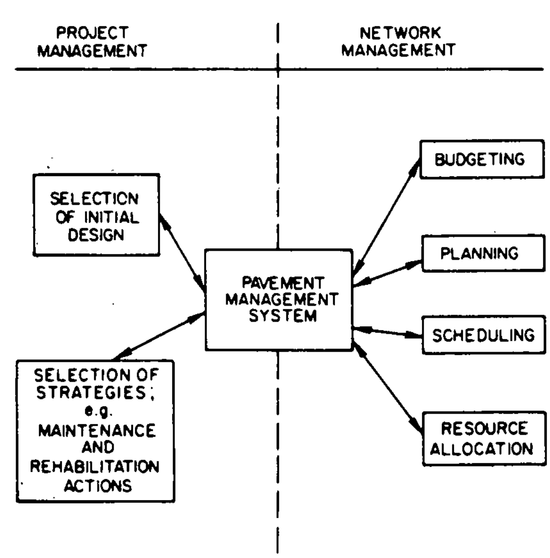


FIGURE 2 Functions of a pavement management system (*1*).

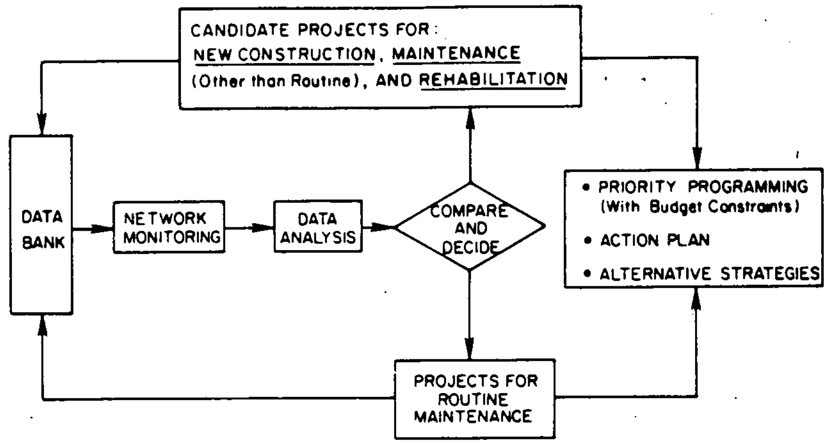


FIGURE 3 Network-level management system process (*1*).

this may be conveniently obtained by means of some type of nondestructive evaluation.

Data Requirements

As indicated above, pavement management systems require large amounts of data that are expensive to collect and input into data processing units. Equipment is available and under development to reduce these costs and improve accuracy and safety. Equipment to obtain data on the following is discussed in this synthesis.

- Structural capacity
- Surface distress
- Friction
- Roughness
- Traffic loading

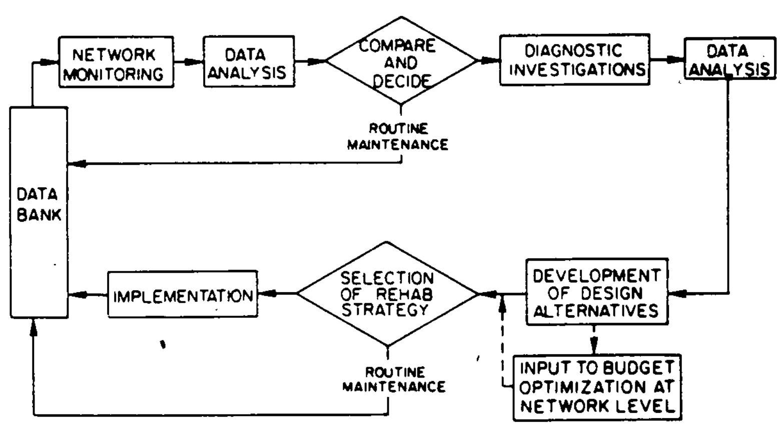


FIGURE 4 Project-level management system process (*1*).

CHAPTER TWO

STRUCTURAL CAPACITY EQUIPMENT

Major reasons for measuring the structural response of the pavement structure (to load) include:

- determination of structural adequacy, which permits the estimation of when rehabilitation should be accomplished so as to maintain performance at a reasonable level, and
- provision of information for use in the design of rehabilitation alternatives.

Because of the fairly lengthy process associated with destructive testing of pavements, a number of procedures and associated equipment for measuring the structural response of pavements nondestructively have been developed in recent years. Equipment in current use generally provides a measure of the surface deflection under slowly moving, vibratory, or falling loads. Table 2 lists examples of this equipment by measurement category. Reports by Bush (*4*) and Smith and Lytton (*5*) provide detailed evaluations of many of these devices. Basic characteristics of the equipment are summarized in Tables 3–5.

SLOWLY MOVING WHEEL LOAD

The most common equipment used to measure the response of pavement to a slowly moving wheel load is the Benkelman beam [termed Deflection Beam by the Transport and Road Research Laboratory of Great Britain (*6*)]. This is a relatively simple device for measuring pavement deflections (Figure 5). The probe of the beam is placed between the dual wheels of a truck axle ballasted to the desired load (e.g., 18,000 lb). Two methods of measurement are used: (a) the load approaches the end of the probe and its deflection is observed (WASHO procedure) and (b) the wheel moves away from the end of the probe and rebound of the pavement is measured (rebound procedure). For asphalt surfaced pavements it should be emphasized that different values for deflection will be obtained from the two methods; for example, data reported by Kingham (*7*) indicate that the rebound deflection is about twice the deflection measured with the California deflectometer (which provides results comparable to the Benkelman beam WASHO procedure).

The California Traveling Deflectometer (Figure 6) is an automated Benkelman beam and permits deflections in both wheel paths to be obtained at 20-ft (6.1-m) intervals uniformly and continuously as the vehicle moves at a speed of 0.5 mph (0.8 km/h).

The La Croix Deflectograph, developed in France, is similar to the Traveling Deflectometer in that it is an automated deflection measuring device. Figures 7 and 8 show the equipment. The frame is placed on the road surface with the probes in front of the dual wheels of the truck. As the truck moves forward, the probe beams rotate; the rotation is measured by transducers. When the wheels have passed the probe tip, the frame and beams are lifted, to be repositioned on the pavement at a distance of 11 to 20 ft (3.5 to 6 m) farther along. The deflectograph operates at a speed of 1.25 to 2.5 mph (2 to 4 km/h) (*5*).

TABLE 2

DEFLECTION MEASURING DEVICES

Load Application Method	Device
Slowly moving wheel load	Benkelman beam (deflection beam)
	Curvature meter
	Traveling Deflectometer (California)
	Deflectograph
Vibratory load, steady state	Dynaflect
	Road Rater
	FHWA (Cox)
	U.S. Army Corps of Engineers (WES Heavy Vibrator)
Falling weight (impulse load)	Dynatest
	KUAB
	Phoenix (Pavement Consultancy Services)

STEADY-STATE VIBRATORY LOADING

Vibratory equipment usually applies a sinusoidal force to the pavement structure, as shown in Figure 9. Deflections are measured with inertial motion sensors (accelerometer or velocity sensors). Two types of vibrator equipment have been used extensively for highway pavement—the Dynaflect and the Road Rater. A third device, which has been used experimentally by the FHWA, was developed by Cox and Sons and uses linear variable differential transformers to measure deflection.

The Dynaflect is a dynamic force generator employing counter-rotating masses to apply a peak-to-peak force of 1,000 lb (4.4 kN) at a fixed frequency of 8 Hz. Force is applied to the pavement through two 4-in. (100-mm) wide, 16-in. (400-mm) diameter rubber-covered steel wheels spaced 20 in. (500 mm) center-to-center (Figure 10). Deflections are measured with five geophones (velocity sensors) on the longitudinal axis through the loading wheels (Figure 11). The equipment is rapid

TABLE 3

SOME CHARACTERISTICS OF COMMERCIALLY AVAILABLE NONDESTRUCTIVE TESTING (NDT) DEVICES (*5*)

Device Name	Principal of Operation	Load Actuator System	Min. Load	Max. Load	Static Weight on Plate	Type of Load Transmission	Method of Recording Data
Benkelman Beam (AASHTO)	Deflection Beam	Loaded Truck Axle	N/A	N/A	N/A	Truck Wheels	Manual
Deflection Beam (British)	Deflection Beam	Loaded Truck Axle	N/A	N/A	N/A	Truck Wheels	Manual
La Croix Deflectograph	Mechanized Deflection Beam	Moving Truck Loaded with Blocks or Water Weight	Empty Truck Weight	Loaded Truck Wheel Weight	N/A	Truck Wheels	Manual, Printer, or Automated
Dynaflect	Steady State Vibratory	Counter Rotating Masses	1,000	1,000	2,100	Two 16" dia. UrethaneCoated Steel Wheels	Manual, Printer, or Automated
Model 400 B Road Rater	Steady State Vibratory	Hydraulic Actuated Masses	500	2,800	2,400	Two 4"by7" Pads with 5.5" Center Gap xxx	Manual, Printer, or Automated
Model 2000 Road Rater			1,000	5,500	3,800	Circular Plate 18" dia. xx	
Model 2008 Road Rater			1,000	8,000	5,800		
KUAB 50 Falling Weight Deflectometer	Impulse	Two Dropping Masses	1,500	12,000	?	Sectionalized Circular Plate 11.8" dia. x	Manual, Printer or Automated
KUAB 150 Falling Weight Deflectometer			1,500	35,000	?		
Dynatest Model 8000 Falling Weight Deflectometer	Impulse	Dropping Masses	1,500	24,000	?	Circular Plate 11.8" dia.	Manual, Printer, or Automated

x Solid Plates and Plates of Other Diameters are Available
xx Plates of Other Diameters are Available
xxx Circular Plates are Available

and can be simply operated with a control unit and microcomputer. Because of the relatively light load applied, extrapolation of the results to heavier loads must be done with care, since many of the pavement components exhibit nonlinear stiffness characteristics.

The Road Rater is a steel mass, hydraulically actuated vibrator capable of producing various magnitudes of dynamic force in the frequency range 5 to 100 Hz (Figure 12). In the Model 400 (Figure 13), for example, when the unit is operated at 25 Hz with a hydraulic pressure of 550 psi (3.8 MPa) and a mass displacement of 0.058 in. (1.47 mm), a force of about 1200 lb (5.3 kN) peak-to-peak is exerted onto the pavement through two steel pads with a total contact area of 56 in.^{2} (360 cm^2). Displacements of the pavement are measured by at least two sensors, one at the center of loading and the others at some distance (Figure 14).

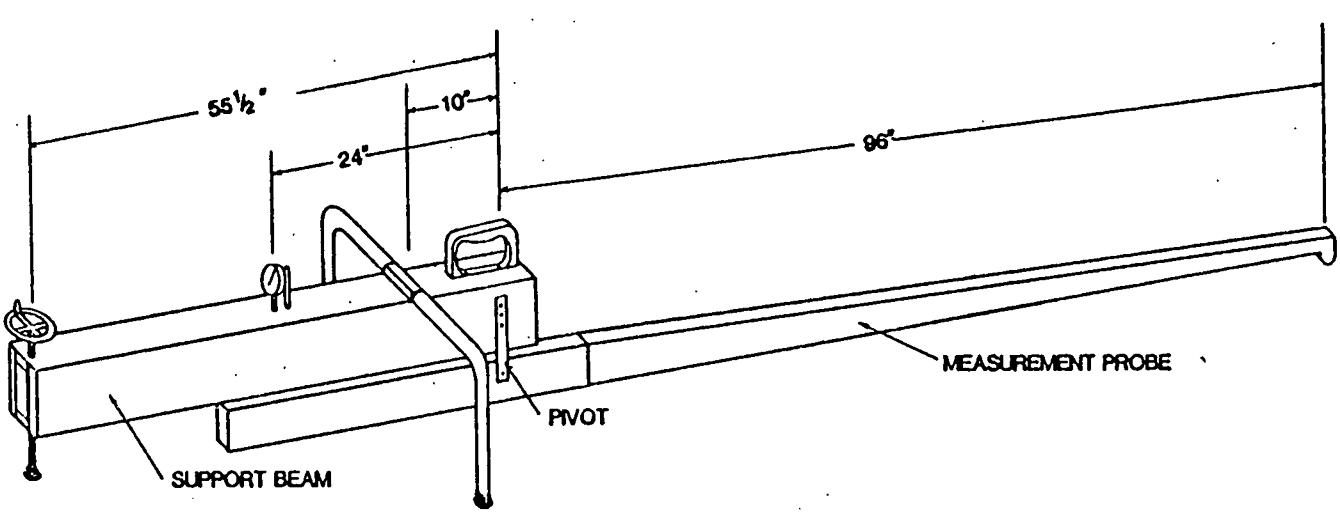


FIGURE 5 Basic components of Benkelman beam.

TABLE 4

MORE CHARACTERISTICS OF COMMERCIALLY AVAILABLE NONDESTRUCTIVE TESTING (NDT) DEVICES (*5*)

Device Name	Type of Carriage	Type of Prime Mover	Basic Cost	Contact Area	Vibratory Freq & Range	Deflection Measuring System	Number of Deflection Sensors	Normal Spacing of Sensors	Load Measuring System
Benkelman Beam (AASHTO)	N/A	N/A	$1,000	N/A	N/A	Dial Indicator	1	N/A	None
Deflection Beam (British)	N/A	N/A	$ 1,500	N/A	N/A	Dial Indicator	1	N/A	None
La Croix Deflectograph	Truck	None	$166,500**	N/A	N/A	Inductive Displacement Transducers	2(one in each wheel path)	N/A	None
Dynaflect	Trailer	Tow Vehicle	$22,185	~32in²	8Hz	Velocity Transducers	5	Center & at 1' Intervals	None
Model 400 B Road Rater			$30,580	56in²			4		
Model 2000 Road Rater	Trailer*	Tow Vehicle	$40,800	254in²	5Hz to 70Hz	Velocity Transducers	4	Center & at 1' Intervals	Load Cell
Model 2008 Road Rater			$64,000	254in²			4		
KUAB 50 Falling Weight Deflectometer	Trailer	Tow Vehicle	$70,000	109in²	N/A	Seismic Deflection Transducers	5	Center & 0.6' to 8.0'	Load Cell
KUAB 150 Falling Weight Deflectometer			$85,000	109in²			5		
Dynatest Model 8000 Falling Weight Deflectometer	Trailer	Tow Vehicle	$86,500	109in²	N/A	Velocity Transducers	7	Center & 0.6' to 7.4'	Load Cell

* Earlier versions of the Model 400 were mounted on vehicles.

** $71,000 without truck but requires 1 to 3 man months to install on purchasers vehicle.

The U.S. Army Corps of Engineers has developed a "heavy" vibrator, for evaluating airfield pavements (Figure 15). A static load of 16,000 lb (71 kN) is exerted and the device is capable of applying a vibratory load of 30,000 lb (130 kN) peak-to-peak (15,000 peak vibratory load) at a frequency of 15 Hz (*8*). With the equipment, a range of frequencies from 5 to 90 Hz can be obtained. At the higher frequencies, however, the load is somewhat diminished. Deflection is measured by a velocity sensor attached to an 18-in. (450-mm) diameter steel loading plate.

FALLING-WEIGHT (IMPULSE) LOADING

The falling-weight deflectometer applies an impulse load to the pavement by dropping a mass from some specific height to the pavement; Figure 16 illustrates this schematically. By varying the height of fall and/or drop weight, the peak force applied to the pavement can be varied. The width of the loading pulse (loading time) is controlled by the buffer characteristics (Figure 16).

Three manufacturers currently market falling-weight deflectometers in the United States (Table 2). Several models are manufactured. Loads applied to the pavement range from about 1,500 to 35,000 lb (6.7 to 156 kN) with a loading pulse in the range of 0.025 to 0.030 seconds.

Equipment manufactured by Dynatest Consulting Inc. is shown in Figures 17 and 18. The Phoenix and KUAB units are shown in Figures 19 and 20. Computer operating systems are commonly used with the available units.

APPLICATION AND DATA USE

As noted at the outset of this chapter, the primary reasons for measuring the structural response of the pavement are to determine the existing load-carrying capacity and/or to use the data to assist in the selection of rehabilitation measures such as overlays.

Table 6 contains a summary of the results of the questionnaire on the uses of deflection measurements by the various states. In general, it will be noted that nondestructive structural testing is used primarily at the project level; that is, for the evaluation of site-specific projects.

Although deflection measurements are primarily used for overlay design, some states have indicated that they use the measurements for load restrictions (particularly in the spring during thaw periods), for detecting voids under p.c. concrete slabs, and for ascertaining the response of p.c. concrete pavements at and near joints (e.g., load transfer).

According to the results of the questionnaire, the majority of the states currently are using either the Benkelman beam or Dynaflect.

OPERATIONAL CHARACTERISTICS

Table 7 provides a summary of the operating characteristics of structural capacity measuring equipment as reported by the states. Although a few states indicated that they use the Dy-

TABLE 5

NONDESTRUCTIVE TEST DEVICE LOADING CHARACTERISTICS

	Frequency Hz	Dynamic Force Range lb_f	Static Weight lb_m	Contact Area $in.^2$	Maximum Dynamic Contact Pressure psi	Maximum Static Contact Pressure psi	Pavement Loading Device
Static							
Benkelman Beam	--	--	9,000	65.0	--	54.5	2 - 10.00 x 20.00 tires, 80 psi
Impulse							
FWD	16.7	0-13,200	556	110.0	120.0	4.6*	30-cm-diam plate, rubber covered
Vibratory							
Dynaflect	8	1,000	2,067	8.6	116.0	240.3	2 - 4-in.-wide, 16-in. O.D. polyurethane-coated rigid wheels spaced 20 in. C.C.
Model 400 Road Rater	(10, 20, 25, 30, 40)	0-800	1,100	56.0	14.2	19.6	2 - 4- by 7-in. rectangular pads
Model 510 Road Rater	(10, 20 25, 30, 40)	0-2,400	1,350	56.0	42.9	24.1	2 - 4- by 7-in. rectangular pads
Model 2008 Road Rater	5-50	0-8,000	4,000	254.0	31.4	15.7	18-in.-diam steel plate
WES 16-kip	5-100	0-30,000	16,000	254.0	118.0	63.0	18-in.-diam steel plate

Note. 1 lb_f = 4.448 N; 1 lb_m = 0.45 kg; 1 $in.^2$ = 6.45 cm^2; 1 psi = 763 kg/m^2; 1 in. = 2.54 cm.

* When falling weight is released, the static weight is reduced by that weight (330 lb); therefore, the pressure would also be reduced to 1.9 psi.

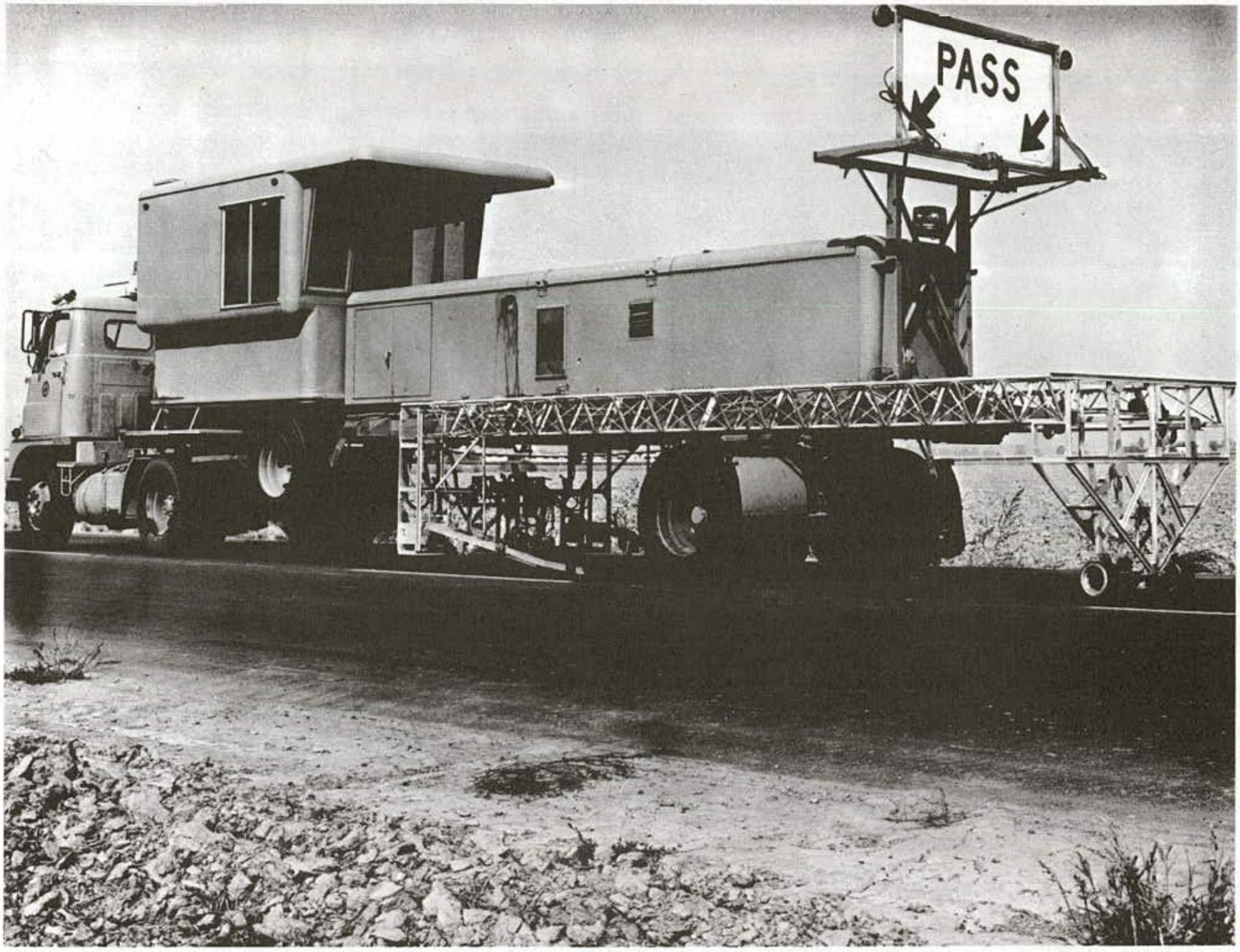


FIGURE 6 California Traveling Deflectometer.

TABLE 6

USES OF STRUCTURAL CAPACITY MEASURING EQUIPMENT

Equipment	States Using Equipment	Use of Equipment				
		Network Management		Project Management		
		Yes	Sometimes	Yes	Sometimes	Other
Benkelman beam	19	0	0	2	3	Overlay design, research, Spring truck weight limits
Dynaflect	18	3	6	11	5	Joint studies, research, voids under PCI, base course stability
Road Rater	6	2	2	4	1	Research, overlay design, load restrictions
Falling-weight deflectometer	6	0	0	2	0	Maintenance, research

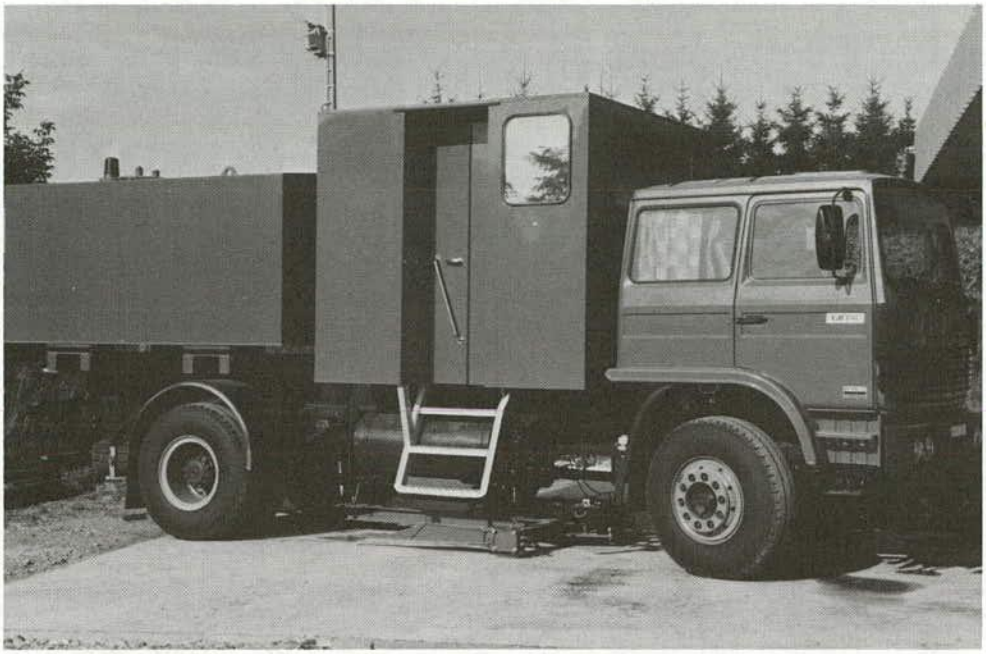


FIGURE 7 LaCroix Deflectograph (MPA, S.A.).

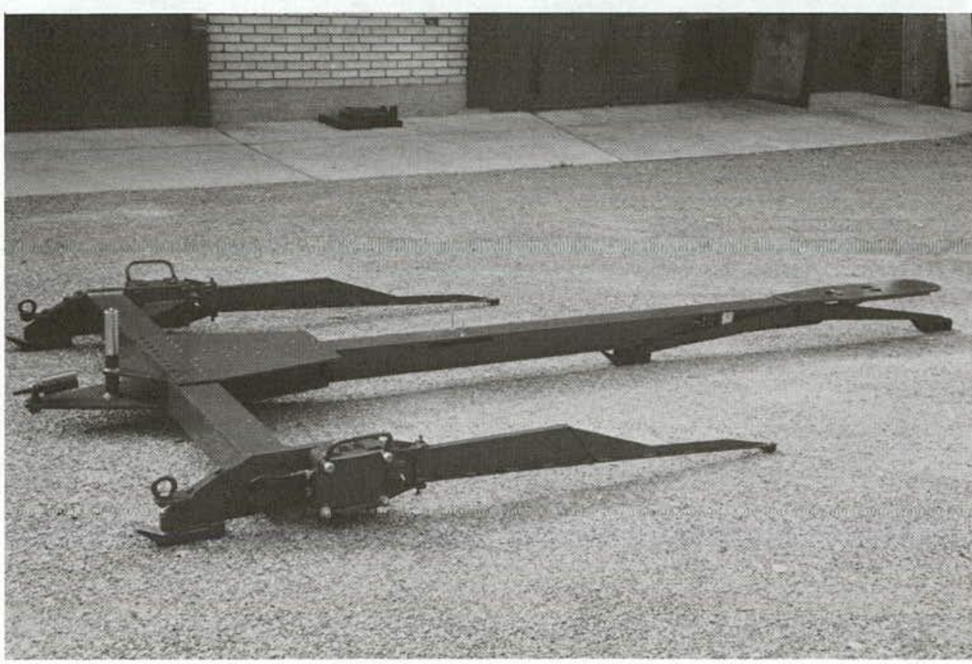


FIGURE 8 Placement frame with displacement probes used for measuring deflection with the La Croix Deflectograph (MPA, S.A. Switzerland).

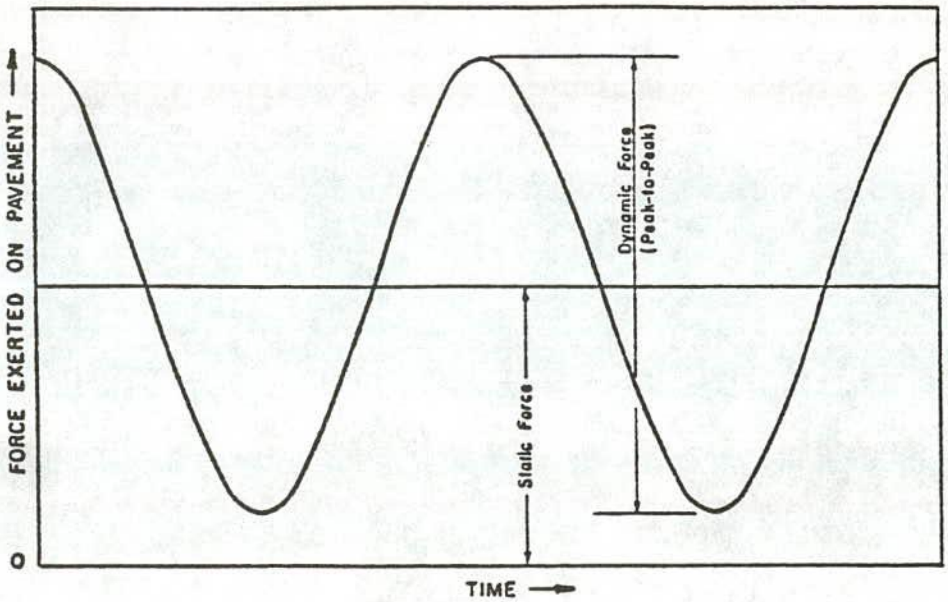


FIGURE 9 Typical output of dynamic force generator (*5*).

FIGURE 10 Dynaflect in operation (SIE, Inc.).

FIGURE 11 Dynaflect Deflection Sensors (SIE, Inc.).

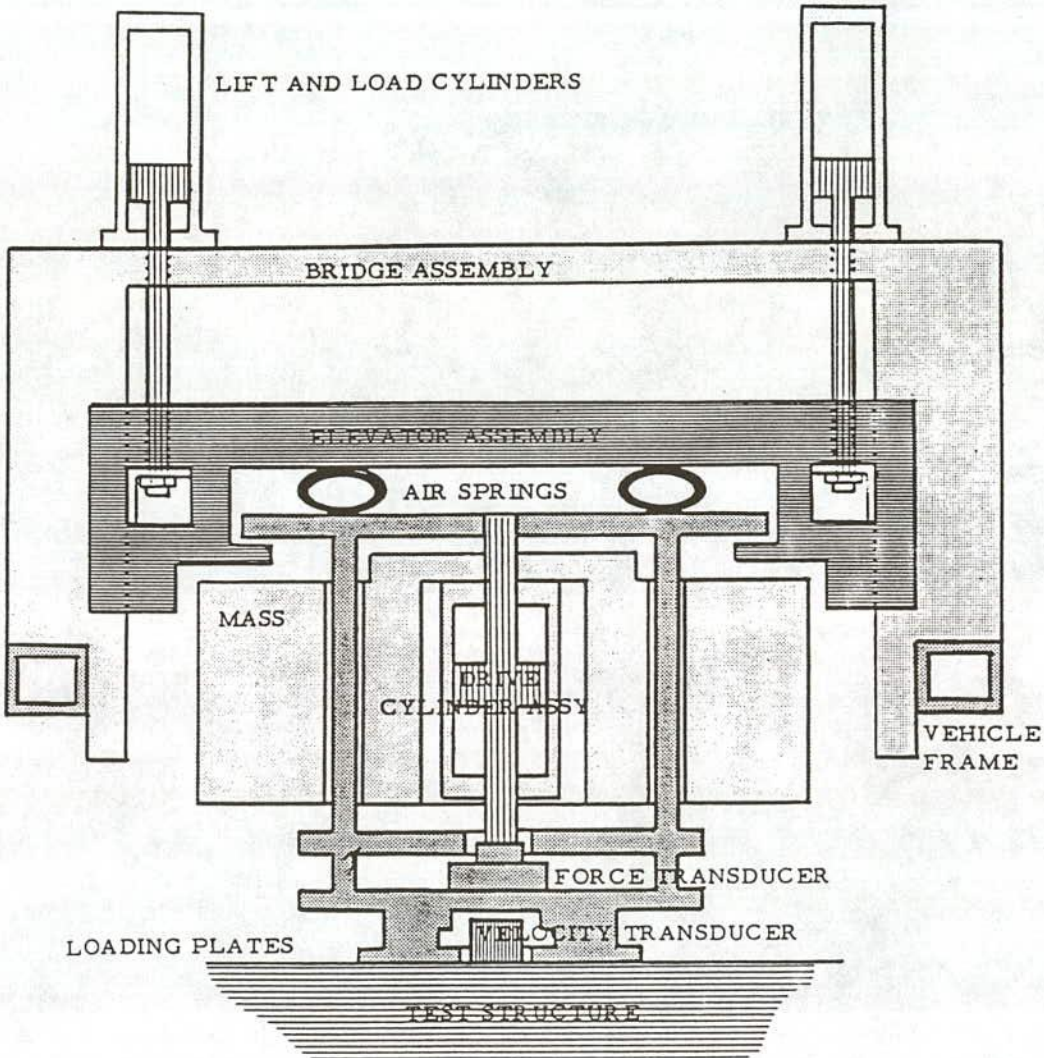


FIGURE 12 Schematic drawing of the Road Rater static and Dynamic loading system (Foundation Mechanics, Inc.).

FIGURE 13 Model 400B trailer mounted Road Rater (Foundation Mechanics, Inc.). (Note that the model 400B can be van mounted.)

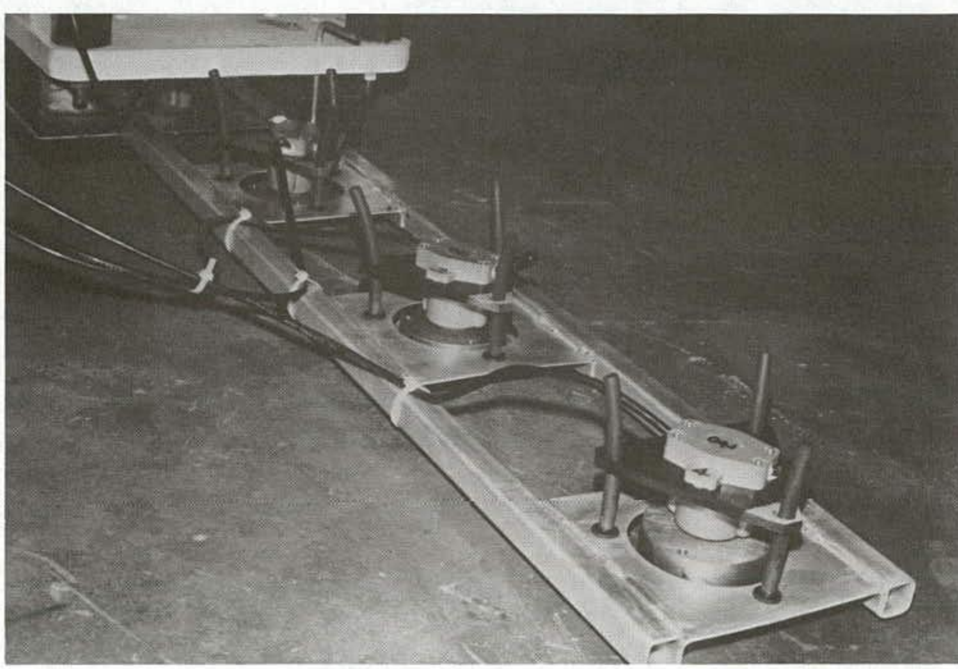


FIGURE 14 Road Rater sensor boom in test position. Sensor No. 1 is visible directly beneath the mass in the upper left of photograph (Foundation Mechanics, Inc.).

TABLE 7

OPERATING CHARACTERISTICS OF STRUCTURAL CAPACITY MEASURING EQUIPMENT

Agency	Data Points per Day: Average	Data Points per Day: Range	Lane Miles of Pavement per Day: Average	Lane Miles of Pavement per Day: Range	Data Points per Lane Mile	Equipment Utilization (Days per Year): Average	Equipment Utilization (Days per Year): Range
Benkelman Beam							
Idaho	40	20 - 60	40	20 - 60	1	5	1 - 20
Illinois	200	160 - 240	10	2 - 14	20	9	7 - 11
Louisiana	30		6		5	10	
Michigan	50		5		10	40	
Missouri	400		4		100	10	
New Jersey	30	20 - 50	1		30	10	5 - 15
New York	160	130 - 285	1	0.75 - 1.75	158	30	20 - 50
Oklahoma	150	125 - 175	30	20 - 40	5	120	80 - 150
Oregon	200	150 - 300	5	2 - 10	23	150	125 - 175
South Carolina	60	40 - 100	6	2 - 10	10	15	10 - 20
Texas	50	40 - 60	1	0.75 - 1.25	26	10	
Summary	125	20 - 300	10	0.75 - 60	35	37	1 - 175
Dynaflect - Network Management System							
Arkansas	175	150 - 250	48	35 - 60	3	100	60 - 140
Idaho	80	60 - 130	50	30 - 65	2	100	
Nebraska	80	60 - 100	80	60 - 100	1	150	100 - 200
Oregon	5					180	
South Dakota	48	40 - 55	49	40 - 55	1	95	90 - 100
Utah	450	350 - 550	90	70 - 110	5	110	
Summary	140	40 - 550	60	30 - 110	2	120	60 - 200
Dynaflect - Project Management System							
Arizona	45	35 - 55	15	10 - 20	3	30	15 - 40
Arkansas	175	150 - 250	48	35 - 60	3	100	60 - 140
California	252	42 - 420	6	1 - 20	21	170	0 - 360
Kansas	120	80 - 150	24	10 - 30	5	110	88 - 130
Nebraska	80	60 - 100	80	60 - 100	1	150	100 - 200
Nevada	450		15		30	120	
South Dakota	48	40 - 55	49	40 - 55	1	95	90 - 100
Texas	210	170 - 250	4	3 - 5	26	100	90 - 110
Utah	450	350 - 550	90	70 - 110	5	110	
Virginia	276	52 - 322	15	5 - 20	18	83	45 - 84
Summary	200	35 - 550	35	1 - 110	9	110	15 - 200
Road Rater							
Illinois	175	150 - 200	5	3 - 7	35	70	35 - 105
Kentucky	400		40		10	40	
Louisiana	210		70		3	45	
Maryland	200	150 - 300	10	5 - 15	13	160	90 - 200
Pennsylvania	110		10		11	75	
Summary	220	150 - 300	35	3 - 70	14	78	35 - 200
Falling-Weight Deflectometer							
Alaska	150		30		5	150	
Arizona	35		11		3	20	
Florida	480		0.75		260	100	
Tennessee	150		35	30 - 40	5	130	
Washington	150	100 - 250	15	10 - 20	10	100	
Summary	190	100 - 250	22	10 - 40	5	80	

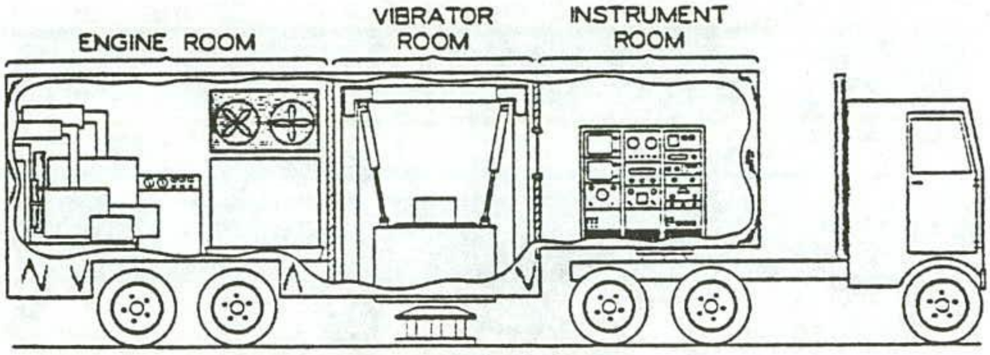


FIGURE 15 16-kip Heavy Vibrator (WES).

naflect for measurements at the network level, the majority of the measurements, as noted earlier, are performed on specific projects for detailed design purposes. Typically 150 to 200 measurements can be made per day with the equipment operated about 100 days per year by the state highway agencies. About 10 to 15 data points are obtained per lane mile of pavement.

The results of other studies are reported in Tables 8–13. In general, the data indicate that the automated equipment permits more mileage to be tested in a specific period than is possible with the Benkelman beam.

COSTS

Cost data and personnel requirements obtained from the questionnaire are summarized in Table 14. The cost data and personnel requirements reported in Table 14 exceed some of those reported by Bush in Table 8 but are similar to the requirements summarized in Tables 9–13. Initial cost data for the various equipment are given in Tables 4 and 15. In general, the data in Table 14 are of the same order as the data contained in Tables 4 and 16 with the Benkelman beam exhibiting the lowest purchase price and the falling-weight deflectometer exhibiting the highest purchase price. Costs per data point are on the order of five dollars.

SAFETY

With the exception of the California Traveling Deflectometer, all currently used structural capacity measuring equipment must be operated at a fixed location on the pavement. This requirement necessitates traffic control and hence safety requirements for the equipment. Current traffic control requirements of various agencies are given in Appendix C (Table C-4). Elaborate costly measures are required under high traffic volumes. Daily traffic control costs generally are within the range of $200 to $500 (Tables 9–13).

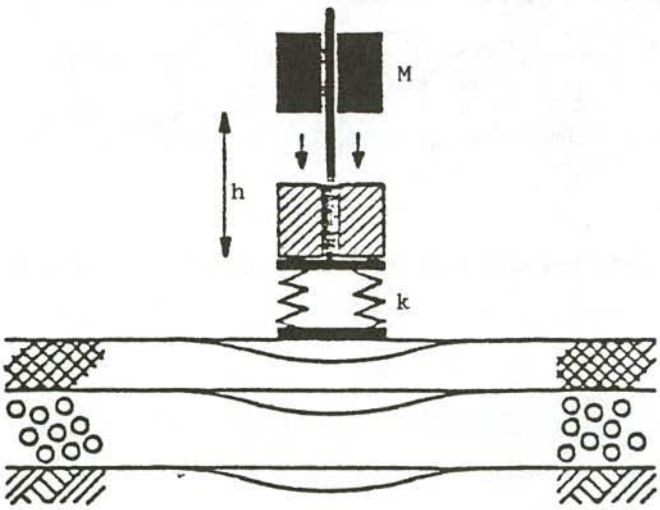


FIGURE 16 Schematic diagram of falling-weight deflectometer (M = mass, h = drop height, k = buffer).

TABLE 8

OPERATION OF DEFLECTION-MEASURING EQUIPMENT (*4*)

Device	Time Requirements		Personnel	
	Daily Set-Up & Calibration (minutes)	Time per test (minutes)	Minimum No.	Optimum No.
Benkelman beam	10	3.25	2	2
Dynaflect				
Standard	20	1.25	1	2
Digital	20	0.75	1	1[a]
Falling-weight deflectometer	20	1.5[a]	1	2
Road Rater				
Model 400	15	1.0	1	2
Model 510	15	1.0	1	2
Model 2008	15	1.0	1	1
WES 16-kip vibrator	60	1.5	3	4

[a]With printer

FIGURE 17 Falling-weight deflectometer (Dynatest Consulting, Inc., Model 8002).

TABLE 9

SELECTED DATA REPORTED BY DEFLECTION BEAM USERS (*5*)

DEFLECTION BEAM

	No. of Persons in Crew	No. of Test Points Per Day	Man-Hours Per Test Day	Cost to Analyze One Day's Data	Analysis Cost Per Point	Average Annual Main. Cost	Average Daily Traffic Control Costs
Illinois	3	100	21	$275	$2.75	--	$275
Virginia	3	50	24	$ 75	$1.50	--	$250
Great Britain	3	100	24	$ 32	$0.32	$42	--
Mean	3	83	23	$127	$1.52	$42	$262
Standard Deviation	0	24	1.4	$106	$0.99	--	$12.50

FIGURE 18 Falling-weight deflectometer in operating position (Dynatest Consulting, Inc., Model 8002).

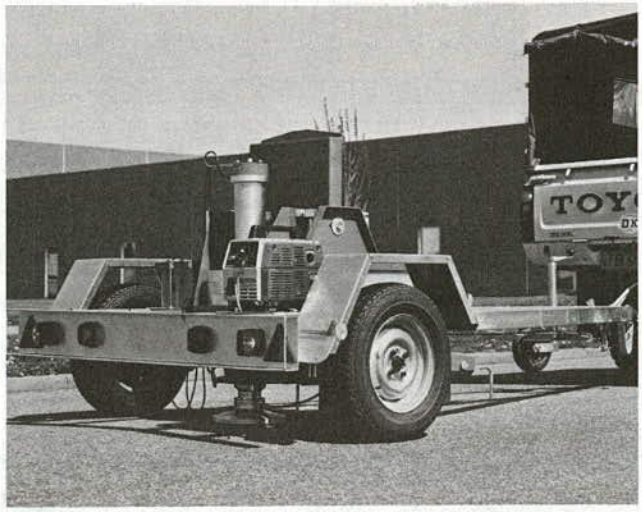


FIGURE 19 Falling-weight deflectometer Model ML 10,000 Phoenix (Pavement Consultancy Services, Inc.)

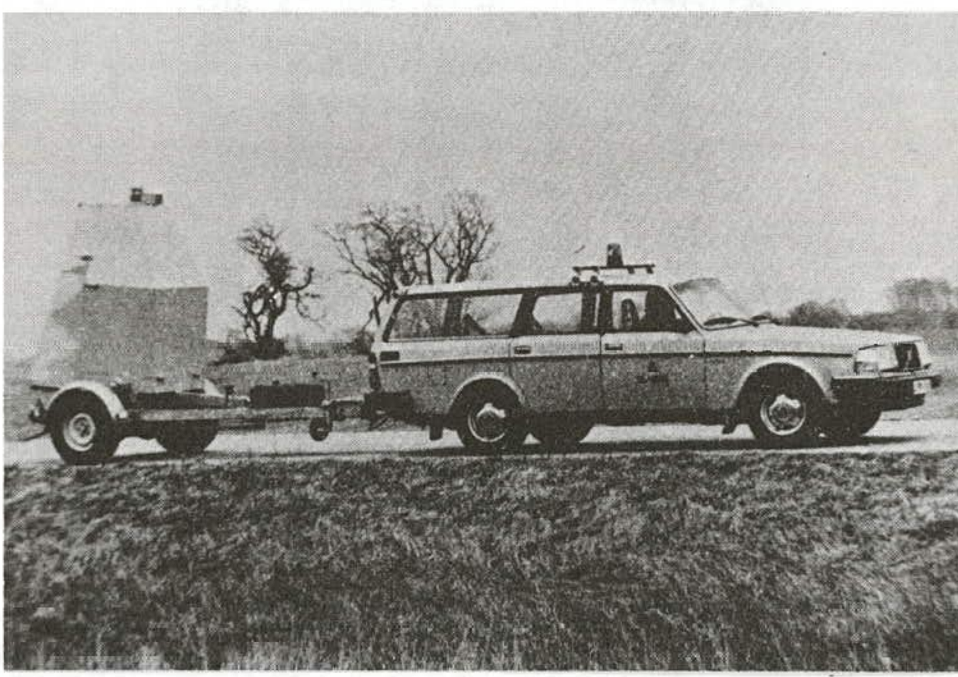


FIGURE 20 KUAB falling-weight deflectometer (courtesy of KUAB Konsult & Utreckling, AB).

TABLE 10

SELECTED DATA REPORTED BY DYNAFLECT USERS (5)

DYNAFLECT	No. of Persons in Crew	No. of Test Points Per Day	Man-Hours Per Test Day	Cost to Analyze One Day's Data	Analysis Cost Per Point	Average Annual Main. Cost	Average Daily Traffic Control Costs
Arizona	2	75	16	$ 25	$.33	$5000	$750
California	1	420	8	$200	$.48	--	$600
Florida	2	300	20	--	--	--	$140
Texas	2	275	16	$ 50	$.18	$ 850	$300
Virginia	1	100	8	$ 75	$.75	$ 875	$250
Mean	1.8	234	14	$ 88	$.44	$2242	$408
Std Deviation	0.5	130	5	$ 67	$.21	$1950	$229

TABLE 11

SELECTED DATA REPORTED BY DYNATEST FALLING-WEIGHT DEFLECTOMETER USERS (5)

FALLING WEIGHT DEFLECTOMETER	No. of Persons in Crew	No. of Test Points Per Day	Man-Hours Per Test Day	Cost to Analyze One Day's Data	Analysis Cost Per Point	Average Annual Main. Cost	Average Daily Traffic Control Costs
Arizona	2	75	16	$ 25	$0.33	$5000	$750
Florida	2	150	16	--	--	--	$140
Minnesota	1.5	250	14	--	--	--	--
Waterways Experiment Station (WES)	2	200	16	$500	$2.50	$1500	$200
Mean	1.9	169	15.5	$262.5	$1.41	$3250	$363
Std Deviation	0.2	65	0.9	$237.5	$1.09	$1750	$274

TABLE 12

SELECTED DATA REPORTED BY ROAD RATER USERS (5)

ROAD RATER	No. of Persons in Crew	No. of Test Points Per Day	Man-Hours Per Test Day	Cost to Analyze One Day's Data	Analysis Cost Per Point	Average Annual Main. Cost	Average Daily Traffic Control Costs
MODEL 400							
Kentucky	1.5	350	12	$300	$0.86	$ 100	$100
Pennsylvania	1	375	8	$100	$0.27	$5600	$200
Mean	1.25	362	10	$200	$0.56	$2850	$150
Std Deviation	0.25	12.5	2	$100	$0.30	$2750	$ 50
MODEL 2000							
Illinois	2	175	14	$550	$3.14	$1600	$200
Minnesota	1	360	8	---	---	----	---
WES	1	200	8	$500	$2.50	$1000	$200
Mean	1.33	245	10	$525	$2.82	$1300	$200
Std Deviation	0.47	82	3	$ 25	$0.32	$ 300	0
ALL MODELS COMBINED							
Mean	1.3	292	10	$362	$1.69	$2075	$175
Std Deviation	0.40	86	2.5	$178	$1.17	$2104	$ 43

TABLE 13

SELECTED DATA REPORTED BY AUTOMATED BEAM EQUIPMENT USERS (5)

TRAVELING DEFLECTOMETER/ DEFLECTOGRAPH	No. of Persons in Crew	No. of Test Points Per Day	Man-Hours Per Test Day	Cost to Analyze One Day's Data	Analysis Cost Per Point	Average Annual Main. Cost	Average Daily Traffic Control Costs
California Travelling Deflectometer	2	1750	16	$200	$0.11	$3000	$600
Great Britain LaCroix Deflectograph	2	3250	24	$435	$0.13	$3625	--
South Africa LaCroix Deflectograph	2	3000	16	$200	$0.07	--	—
Mean	2	2667	18.7	$278	$0.10	$3312	$600
Std Deviation	0	656	3.8	$111	$0.02	$ 312	—

TABLE 14

FIRST COSTS AND OPERATING COSTS OF STRUCTURAL CAPACITY MEASURING EQUIPMENT

	Operating Costs ($)					
	Per Data Point		Per Lane Mile of Pavement		Operating Personnel Required	Purchase Price ($)
Agency	Average	Range	Average	Range		
Benkelman Beam						
Idaho	10.00		10.00	5.00 - 15.00	6	
Illinois	1.55		31.00		3	
Louisiana	4.27				2	
Missouri	1.50		150.00		7	
New York	2.00	1.00 - 5.00	6.00	3.00 - 8.00	3	
Oklahoma	2.36	2.25 - 2.50	11.80	11.25 - 12.50	6	
Oregon	3.20	2.10 - 4.30	80.00	64.00 - 320.00	5	
South Carolina	4.00	3.00 - 5.00			3	
Texas	2.00	1.00 - 3.00	100.00	75.00 - 125.00	1	
Summary	3.00	1.00 - 5.00	55.00	3.00 - 320.00	4	200 - 1,000
Dynaflect - Network Management System						
Arkansas	1.84	1.50 - 2.50	5.52	3.65 - 9.20	2	
Idaho	13.00	10.00 - 20.00	130.00	90.00 - 150.00	5	
Oregon	120.00					
South Dakota	6.25	6.00 - 6.50	6.25	6.00 - 6.50	2	
Utah	1.25	1.15 - 1.35	1.25	1.15 - 1.35	2	
Summary	3.11	1.15 - 20.00	4.34	1.15 - 150.00	2	20,000 - 35,000
Dynaflect - Project Management System						
Arizona	20.00		60.00		3	
Arkansas	1.84	1.50 - 2.50	5.52	3.68 - 9.20	2	
California	1.15	0.85 - 5.50	24.15	18.35 - 367.00	1	
Kansas	15.00	10.00 - 19.00	75.00		1	
Nevada	0.78	0.58 - 1.17	23.31	17.48 - 34.96	2	
South Dakota	6.25	6.00 - 6.50	6.25	6.00 - 6.50	2	
Texas	1.00	0.60 - 1.40	50.00	30.00 - 62.00	2	
Utah	1.25	1.15 - 1.35	1.25	1.15 - 1.35	2	
Virginia	1.00	0.80 - 8.00	17.50	10.00 - 15.00	1	
Summary	5.36	0.78 - 18.00	29.22	1.15 - 367.00	2	20,000 - 35,000
Road Rater						
Iowa	6.31		18.92		4	
Maryland	2.76	1.80 - 3.00	55.29	45.00 - 65.00	2	
Pennsylvania	8.00		88.00		3	
Summary	5.69	1.80 - 8.00	54.07	18.92 - 88.00	3	25,000 - 35,000
Falling-Weight Deflectometer						
Alaska	2.00		7.00		2	
Arizona	25.00		75.00		3	
Tennessee	3.00	2.50 - 3.00	12.00	10.00 - 14.00	2	
Washington	3.75	2.24 - 5.60	54.00	28.00 - 112.00	2	
Summary	8.43	2.00 - 25.00	37.50	7.00 - 112.00	2	30,000 - 110,000

TABLE 15

EQUIPMENT COSTS

Device		Cost ($)
Benkelman beam		666
Dynaflect	with standard control unit	16,000
	with digital control unit	19,333
Falling-weight deflectometer		28,000
Road Rater	Model 400A (without vehicle)	22,000
	Model 2008	40,000

MAINTENANCE REQUIREMENTS

Appendix C (Table C-5) summarizes maintenance requirements associated with the operation of structural capacity measuring equipment. As noted, the Benkelman beam requires little or no maintenance. Problems experienced with the Dynaflect include those associated with lowering the load wheels and sensor bar, wearing of moving parts associated with the force wheels, and various electrical problems including sensors.

Problems associated with the Road Rater include hydraulic leaks and sensor and electrical problems. Falling-weight deflectometers have been used on a limited basis. Reported problems include those associated with the pressure switch and electrical sensor problems. Average annual maintenance costs range from about $50 for the Benkelman beam to more than $3,000 for the falling-weight deflectometer and traveling deflectometer (Tables 9–13).

EQUIPMENT DEVELOPMENTS

Equipment is being marketed to measure pavement layer depth, to measure delamination of bridge decks and concrete pavement, to identify voids under pavements, and to detect the presence of stripping in asphalt pavements. Devices using infrared thermography and radar are shown in Figures 21–23. Some of this equipment is van mounted and can operate at speeds exceeding 20 miles per hour (32 km/h). Computerized controls and analysis systems are integral parts of two of the systems.

Pavement structural evaluation by interpretation of surface waves is in the research stage at the University of Texas (*9*). The Federal Highway Administration's Accelerated Loading Facility may also be used for project management systems on a selected basis (Figure 24).

FIGURE 21 Remote sensing using infrared thermography and ground penetrating radar (Donohue and Assoc.).

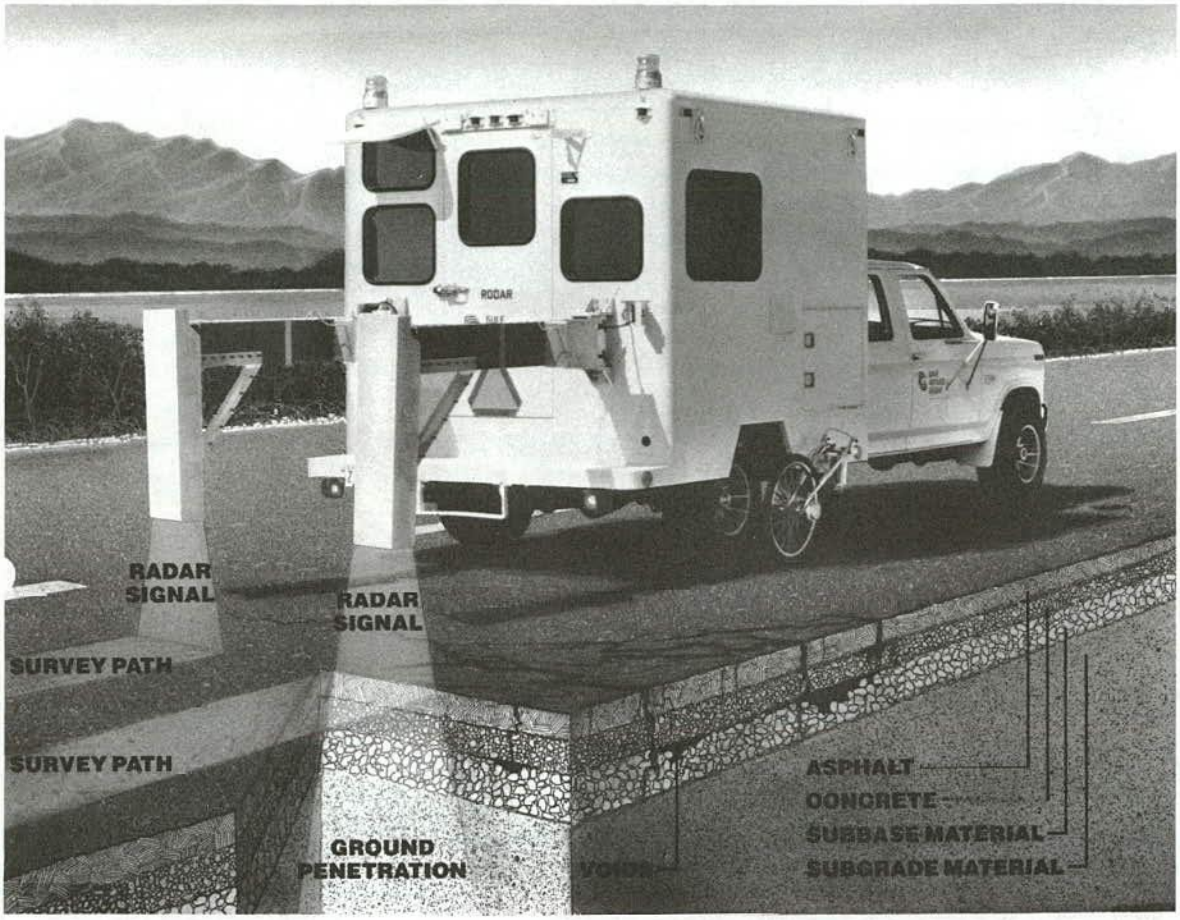


FIGURE 22 Ground penetrating radar unit in operation (Gulf Applied Radar).

TABLE 16

OPERATING CHARACTERISTICS OF PHOTOLOGGER EQUIPMENT

Agency	Data Points per Day		Lane Miles of Pavement per Day		Data Points per Lane Mile	Equipment Utilization (days per year)		Operating Personnel Required	First Cost
	Average	Range	Average	Range		Average	Range		
Kansas	30,000		300		100	50		2	
New York	15,000	5,000 - 25,000	150	50 - 250	100	125	75 - 175	2	
Ohio	10,000	3,000 - 15,000	100	30 - 150	100	120	60 - 180	2	
South Dakota		15,000 - 22,500		150 - 225	100			2	
Wisconsin			150		100	180		3	
	Cost per Data Point		Cost per Lane Mile						
Costs ($)		0.08 - 0.18		8.00 - 25.00					80,000 - 100,000

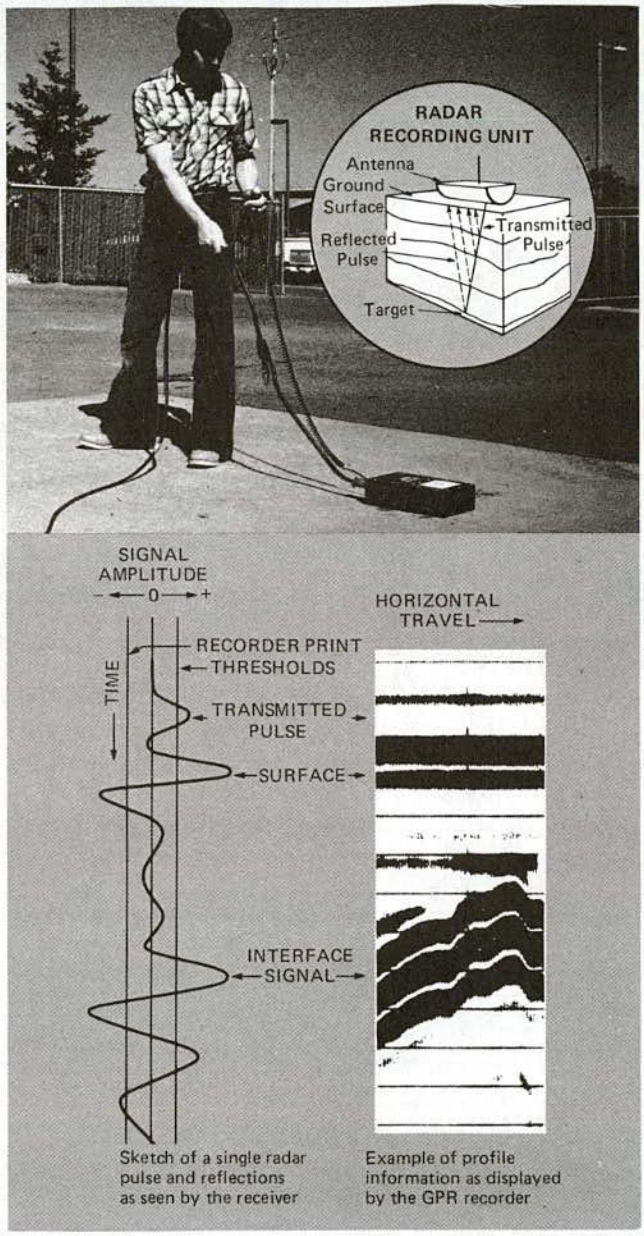


FIGURE 23 Ground penetrating radar (Geophysical Survey Systems, Inc. and Harding Larson Associates).

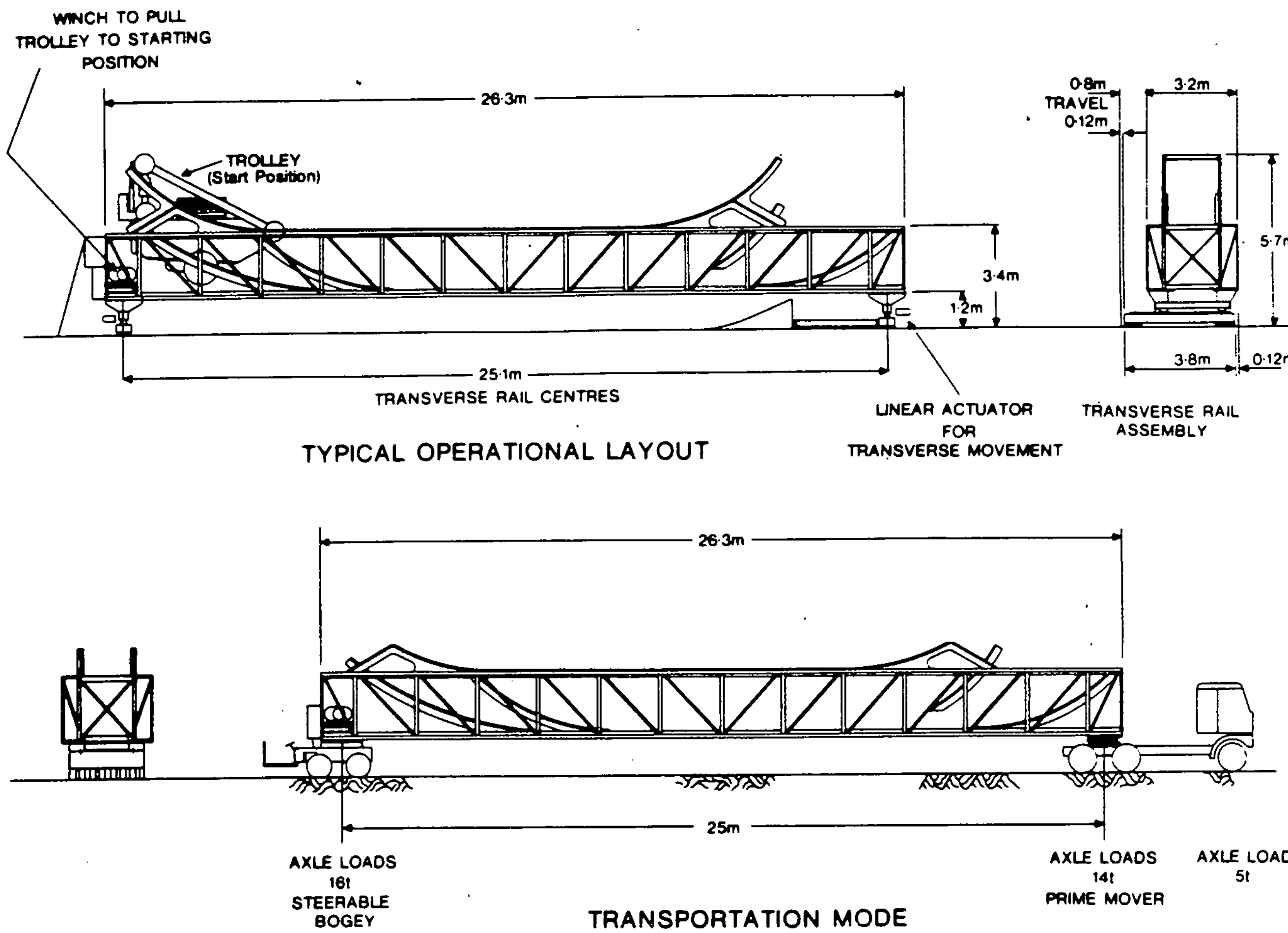


FIGURE 24 Federal Highway Administration's accelerated loading facility (ALF).

CHAPTER THREE

SURFACE DISTRESS MEASURING EQUIPMENT

Pavement distress, a measurement or indication of structural condition, is generally considered by engineers to be at least as important as functional performance (i.e., roughness). Physical distress is identified by the severity and extent of the various modes or types. Usually such distress is broadly associated with: (a) environment; (b) traffic; or (c) materials. This is not to say that the respective types of distress are completely independent; however, in most cases one or the other will be dominant. For example, low-temperature transverse cracks are caused by excessive thermal stresses with virtually no contribution from traffic. However, low-temperature transverse cracks can contribute to roughness and could introduce a condition that would lead to load-associated (alligator) cracking.

Techniques for measuring physical distress as well as types of distress catalogued vary from agency to agency and depend on the purpose for which the information is being collected. Collections of such data are termed condition surveys and engineers often collect more information than required simply because it *may* prove to be of value. It is expensive to collect and manage data; therefore, careful evaluations are necessary before a commitment to collect data is made.

A key question that should be asked before deciding to collect physical distress data is: how does such information relate to the decision-making process? For example, will the type, extent, or severity of distress trigger an action? If the answer to that question is no, the information should not be included unless it is required by the prediction models needed in a pavement management system. The selection of influence variables for prediction models is a research activity involving detailed studies of a limited number of pavement sections. The results of such a study would influence the type of data to be collected. The type of data collected may depend on the properties of pavement materials and the environmental characteristics and maintenance practices. For example, if longitudinal cracking is a good predictor of alligator cracking, then both types of distress should be catalogued; assuming prediction models are to be developed for pavement management.

A major concern in collecting information pertinent to physical distress is the reliability (accuracy and repeatability) of the data because this information is necessarily based on subjective observations. Most systems provide guidelines for identification of the various types, extent, and severity of distress. But even with guidelines, the accuracy and repeatability of the data may not be adequate for some uses of the data at the project level. A procedure prepared for California conditions is typical (*10*). A good overview of procedures currently in use in the United States, Canada, and Australia may be found in References *11–14*.

A major consideration in all of the procedures used for distress surveys is productivity versus precision. In monitoring a large mileage it is often better to sacrifice some precision in order to obtain the necessary productivity. This is particularly true for network-management purposes. Thus, it becomes necessary to limit the types of observations to the bare essentials.

Efforts to automate both the collection and transfer of data to the central computers are being pursued and should be encouraged. Automatic recording equipment is commercially available but is not universally adaptable to a particular user's computer hardware. Expert evaluations are required before purchasing this type of equipment. Equipment of this type can also be "tailor made" (designed) for specific applications.

FIELD PROCEDURES

A number of factors must be considered in planning and implementing procedures for conducting pavement condition surveys. These include (a) determination of homogeneous sections; (b) type, density, and severity of conditions to be catalogued; (c) productivity requirements (continuous vs. sampling procedure); (d) training; (e) quality assurance; and (f) data processing.

Homogeneous section determination refers to the selection of sections that are performing essentially alike and with similar traffic characteristics. For example, in surveying two miles of pavement, it is possible that the first mile may be exhibiting a uniform amount of rutting, while the second mile may have virtually no rutting. These two segments should be surveyed separately, otherwise the results will not reflect the conditions in the field.

Two procedures are often used as guidelines for subdividing pavements into suitable segments: (a) by project length and (b) by predetermined maximum lengths.

Project length refers to the length of the first construction project (e.g., new construction, reconstruction, or overlay). Thus, a project could vary in length from less than a mile to several miles. It is quite possible that when projects become long there can be systematic variations in their performance. In such cases, it is necessary for the rater (the person making visual observations) to recognize these systematic variations and to subdivide the section into homogeneous segments. This is often difficult to do and places a significant responsibility on the rater.

A disadvantage in variable-length segments is in the possible misleading interpretation of the condition survey data. This possibility results from the fact that most condition surveys are made in terms of the density or extent of various distress types. For example, alligator cracking is usually expressed as a percent of the length of a segment or the percent of the area exhibiting this type of cracking. If one observes 500 ft^2 (46 m^2) of cracking in a segment with a total area of 5,000 ft^2 (460 m^2), it would be catalogued as 10 percent, usually not enough to trigger an action. If the total area of the pavement was 2,500 ft^2 (230 m^2), the percentage would be 20 percent, which could be enough to trigger at least some type of maintenance.

In predetermined length procedure, pavements are divided into standard lengths (segments) and each segment is assumed to be homogeneous in performance. The risk in such a procedure is that the sections may not be homogeneous; however, if the lengths are relatively short, the error can be considered acceptable.

For state systems, a "mile-by-mile" maximum length has been used by a number of agencies. The actual segments may not be exactly one mile in length; however, as nearly as possible, they are terminated at political boundaries. Route number changes or construction limits may dictate some segments that are less than or greater than a mile in length.

For cities, a block-by-block approach has been used. If the blocks are too short, combinations of contiguous blocks are appropriate.

For counties, a combination of the mile-by-mile (rural) and block-by-block (urban) approaches may be required. Interpretation of the results to reflect this combination will be necessary, but is possible.

There are no rules on criteria to use in establishing segment lengths; however, this is a very important determination and requires thoughtful consideration before establishing field procedures.

Type, Density, and Severity of Distress

Type, density, and severity of distress involves visual observations and recording of the physical condition of the roadway. This type of information is useful for measuring the overall condition (health) of the pavement network, for ranking pavement segments with regard to their relative condition, and for determining candidate projects in need of rehabilitation and maintenance.

Figure 25 illustrates one form that can be used to record visual observations. Other forms can be developed, but the type of information collected should be similar to that noted in Figure 25.

Determination of extent (density) and severity is essentially subjective depending on experience and engineering judgment in a particular area. In most cases, extent can be assigned to three levels (intervals). The most common intervals are: 1–25 percent, 26–50 percent, and greater than 50 percent. These percentages are usually expressed in terms of total pavement area or as a percent of the length of the segment. Provisions should also be made for a "not observed" category. This is a means of ensuring that the rater(s) have checked for each distress type. One exception to the three levels for distress can be considered for alligator cracking, where four levels are useful because of the critical nature of this type of distress. Transverse cracking is usually categorized by frequency per station or by average spacing.

The severity of distress can be catalogued by categories such as slight, moderate, and severe. Typical definitions for each level of severity are given as follows:

Slight—crack widths less than ⅛ in. (3 mm) or hairline; it can also be based on when maintenance is required (e.g., no maintenance for at least 3–5 years).

Moderate—crack widths between ⅛ in. and ¼ in. (3 and 6 mm) or maintenance within 1–2 years.

Severe—crack widths greater than ¼ in. or maintenance within 1 year or cracks that are spalling with evidence of pumping.

All terms and procedures need to be defined and described in a user's manual, which should be carried with the raters in the field.

Productivity Requirements

Continuous surveys versus sampling refers to the proportion of the segment that is to be rated in the field as part of the condition survey. In general, if the segments are short (e.g., block-by-block), the survey can be continuous; if the segments are long (e.g., mile-by-mile), a sampling procedure may be preferred.

A continuous survey means the raters will attempt to summarize the conditions observed over the entire length of the segment. A sampling survey means that one or more sampling units of equal size will be evaluated. The sample(s) are then assumed to reflect the condition of the segment. The minimum time required to evaluate a sample unit is about 3 to 5 minutes. For project-level decisions, it may be necessary to spend 15 to 30 minutes per sample depending on the amount of distress observed. Thus, the number of sample units will depend on the personnel resources available for evaluation and the number of segments to be evaluated. At *least* three sample units per mile are recommended to estimate the condition of the segment. The location of the sample units is usually made by the use of random tables to select location coordinates. For project-level decisions associated with a failure investigation or for rehabilitation design, a continuous survey is recommended (but in no case less than 25 percent of the pavement area).

Training

Training of the raters is an important aspect of pavement evaluation. Because of the need for fast but reliable estimates of distress, it is necessary to provide a well-organized training program for assigned personnel. This training will involve classroom familiarization with objectives, definitions, and procedures followed by field observations under controlled conditions. User's manuals should also be provided as a field reference for evaluation procedures. The user's manual should contain descriptions of each distress type, how density and severity are to be identified, and procedures for recording information.

Experience indicates that training sessions should be repeated just before rating periods. If multiple teams are to be used, it will be important to "calibrate" the teams so that consistent ratings are obtained. This can be accomplished by repeatedly rating identical sections by each team until similar results are

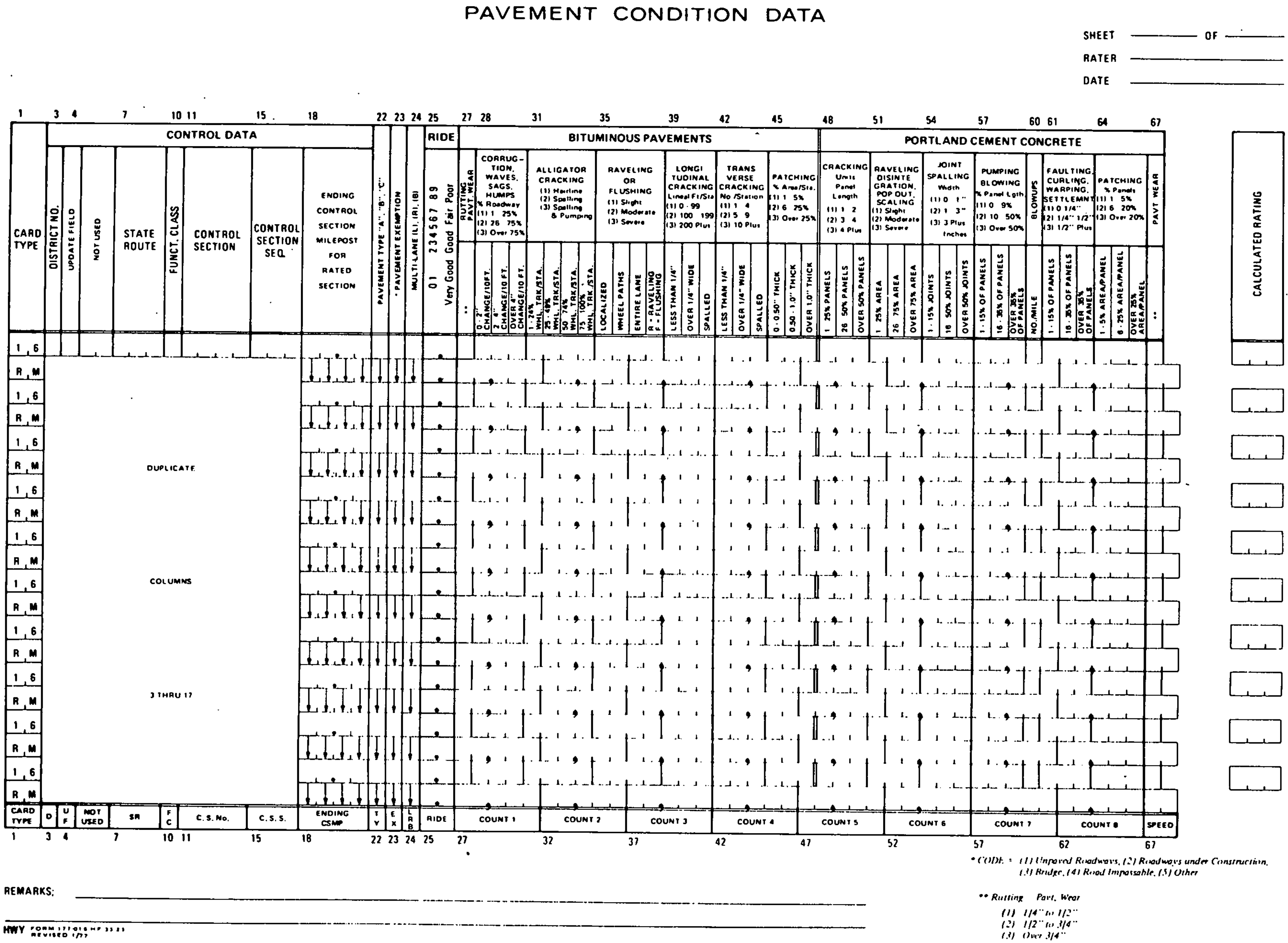


FIGURE 25 -Pavement distress recording form (Washington DOT) (*3*).

obtained. Wide variations have been experienced between rating teams on individual projects but when averages for a group of projects are compared between teams, the variation is significantly reduced. Criteria for evaluation are not available; hence, some judgment must be applied. It is recommended that at least 10 sections be included as the base case. Each section should have a different amount of distress by type, extent, or severity.

Quality Assurance

Quality assurance refers to checks made after surveys have been completed. This step involves obtaining field reports on a sample of the segments evaluated and comparing the observations recorded with a walking survey of the segment or of the sample units. A two to three percent sample should be sufficient to evaluate the reliability of the survey. Because no criteria are available for evaluation, the judgment of experienced engineering personnel must be used. A team from the central office should be responsible for quality assurance. Regional evaluation teams may bias results.

DATA PROCESSING

Pavement evaluations will generate a considerable amount of information. To identify, store, sort, retrieve, and report this information in a usable form, a computer of some type will be required. Attempts to collect this information into standard files or by card index procedures have generally proved to be unsatisfactory. The exact size of the computer will vary depending on the amount of data to be collected, the number of computations required, and the number and types of reports needed. The assistance of a computer expert is recommended.

EQUIPMENT

Currently, the majority of condition surveys are performed visually and relatively little automated equipment is utilized (Appendix D). Hand-held automated recording equipment is utilized in California and Pennsylvania for conducting condition surveys.

Photologging equipment has been used by a number of states for several years (*15*). Several foreign countries also make extensive use of this equipment. Photologgers are used for pavement condition surveys, accident investigation, court testimony, traffic and signing studies, and roadside safety studies.

Transfer of pavement distress type, extent, and severity from photographs or other images to a digital form for establishing pavement condition scores has proved to be both time-consuming and expensive. Typically, photologging is used to determine pavement condition only on high traffic volume roadway sections.

Photologging equipment utilized by the state of South Dakota is shown in Figure 26. European photologging equipment is shown in Figures 27 and 28. Synthesis 94 (*15*) contains an excellent summary of information on photologging equipment.

Operational Characteristics

Operational characteristics of photologging equipment for the states reporting use of this equipment to measure surface distress are contained in Table 16. From 100 to 300 lane miles (160 to 500 km) of pavement can be covered in one day's time, about the same mileage per day that can be currently evaluated by visual condition surveys.

Costs

First costs plus operating costs for the photologging equipment are summarized in Table 16. Operating costs are about $10 to $20 per lane mile ($6 to $12/km).

Maintenance Requirements

Various camera-related problems have been associated with the use of photologgers (Table D-5). Costs range from $200 to $2000 annually.

SAFETY FEATURES

Visual condition surveys with two-person survey teams can often be conducted without elaborate signing and lane closures. The vehicle used by the survey crew should contain all necessary safety lighting and the survey crew should wear vests and hard hats. A high traffic volume facility may require lane closure if detailed condition surveys are to be performed on other than travel lanes (Table D-4).

Photologging equipment can be operated at near traffic speeds. A follow vehicle with appropriate signs and lights is recommended for high traffic volumes.

EQUIPMENT DEVELOPMENTS

Several relatively new items of equipment have been developed in the last several years to aid in evaluating the distress condition of pavements. Some companies are developing systems based on video imaging processing (Earth Technology Corporation; Tessco, Inc.; and KLD Corporation). It is hoped that crack counts can be made and digitized with the equipment.

Several companies have developed equipment that is capable of measuring a number of data items. The Dynatest 500 Roughness and Distress Meter provides a roughness measurement and can record up to eight forms of distress.

The Novak, Dempsey and Associates Laser Road Surface Tester uses 11 lasers along the front bumper and 4 high-speed lasers on the back bumper to perform crack survey, macrotexture investigation, longitudinal profile survey, rut-depth measurement, and cross profile plots. The equipment is shown in Figure 29.

Highway Products International manufactures a Portable

FIGURE 26 South Dakota photologging equipment.

FIGURE 27 GERPHO photologger (MAP, S.A.).

Universal Roughness Device (PURD) (Figure 30) and Automatic Road Analyzer (ARAN) (Figure 31). The PURD is capable of measuring roughness and rut depth and can record up to 20 forms of distress. The ARAN unit can measure roughness, rut depth, transverse profile, grade and crossfall, and curve radius and can record up to 20 forms of distress. A photologging option is also available. Ultrasonic transducers, accelerometers, and computer hardware and software form the basis of these systems.

The PASCO Corporation (Japan) has developed a road survey system that acquires photographic and digital data (cracking, rutting, roughness) at highway speeds.

FIGURE 28 Cameroute in operation (MAP, S.A.).

(a)

(b)

FIGURE 29 Laser Road Surface Tester uses (a) 11 lasers on the front bumper and (b) 4 lasers on the rear bumpers (Novak, Dempsey and Associates).

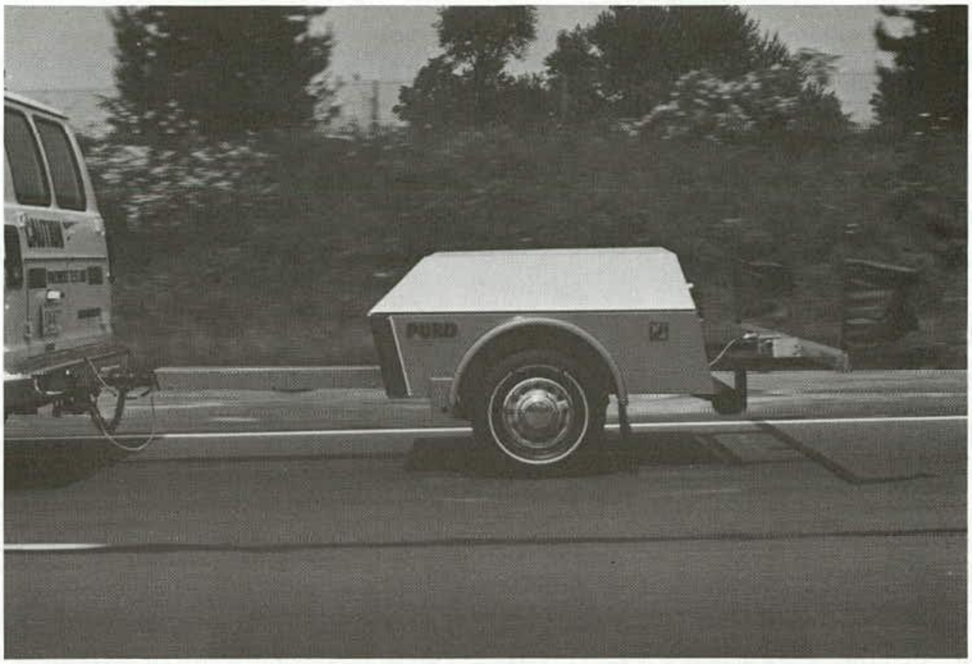


FIGURE 30 Portable universal roughness device (Highway Products International).

FIGURE 31 Automatic road analyzer (Highway Products International).

CHAPTER FOUR

FRICTION MEASURING EQUIPMENT

Pavement friction is the force developed when a tire that is prevented from rotating slides along the pavement surface (*16*). More commonly, it is thought of as a pavement property and defined by:

$$f = \frac{F}{L} \quad (1)$$

where

f = friction factor
F = frictional resistance to motion at the pavement surface, and
L = load normal to pavement surface.

Strictly speaking, it is incorrect to say that the pavement has a certain friction factor unless all details involved in the tire sliding on the pavement are defined. Accordingly, standards have been introduced—an example of which is the friction number, FN, developed by ASTM and defined as:

$$FN = 100\,f = 100\,\frac{F}{L} \quad (2)$$

where F is obtained in a precisely defined manner (usually at 40 mph). An important aspect of safety has been traditionally related to some level for the coefficient of friction (or friction number, etc.). However, there exists the question concerning the relevancy of these measurements to the occurrence of accidents (*17, 18*) as accidents are dependent on a number of factors including the driver, roadway characteristics, vehicle and vehicle components, and weather.

Thus, although surface friction may not be a sufficient safety indicator, most agencies collect accident information, which is entered into the data bank in order to identify high-accident locations and potentially unsafe pavements.

Friction resistance can be determined in a number of different ways:

1. Locked-wheel trailer methods. Usually the ASTM Method E 274 is prescribed in which the tire, the method of applying water to the pavement, the speed (40 mph), etc., are specified.
2. Use of tires in other than the locked-wheel mode, e.g., the yaw mode, to determine a sideways friction factor. Examples of equipment are the SCRIM machine developed by the TRRL (*19*) and the Mu meter.
3. Portable skid testers (*20, 21*)
4. Automobile methods, e.g. braking with diagonal pair of wheels and measuring distance traveled from a specific speed to a full stop.

The majority of pavement friction measurements are made either by the locked-wheel-trailer procedure or by the yaw mode procedure (Table 17). To a first approximation, the maximum sideways friction factor and the maximum braking friction factor for the same tire on the same surface can be considered the same (*16*). Only these two types of equipment will be described here.

LOCKED-WHEEL-TRAILER PROCEDURE

Generally, the equipment consists of a towed trailer as detailed in ASTM E 274. A standard tire is prescribed (ASTM E 501). The trailer is towed at a speed of 40 mph (64 km/h) over the dry pavement and water is applied to the pavement ahead of the test tire. The braking system is actuated to lock the test tire. Equipment is included to measure the friction force generated when the tire is locked and the vehicle and trailer are running at the prescribed speed. The locked-wheel trailer is the most commonly used friction measuring equipment (Table 18). Forty states use this device; those shown in Figures 32 and 33 are representative of equipment in this category.

YAW MODE (MU METER) PROCEDURE

Figure 34 illustrates an example of equipment that measures the coefficient of friction between tire and pavement in the yaw mode. This device uses two yawed wheels with smooth tires and measures the side force developed by both. No restraining mechanism is required to keep the vehicle in a straight line since the tires are yawed at opposite, equal angles. This is illustrated in the schematic diagram of Figure 35.

APPLICATION AND DATA USE

Table 18 indicates that the equipment is used for both network-level and project-level decisions. Generally, the practice in the United States consists of measuring a particular section on the highway system biennially. If special conditions are encountered (e.g., high accident site), monitoring may be done more frequently.

It should again be emphasized that friction number values below prescribed levels do not by themselves indicate that some

TABLE 17

USE OF FRICTION MEASURING EQUIPMENT

Equipment	No. of States Using	Use of Equipment: Network Management Yes	Network Management Sometimes	Project Management Yes	Project Management Sometimes	Other Uses
Locked-wheel skid trailer	40	22	8	13	16	Accident investigation; Research; Experimental paving materials
Mu Meter	4	2	0	2	2	Accident investigation
British Pendulum	2		1		1	Used where skid trailer cannot operate

form of remedial action is required. Generally, information on accidents should also be included in the data bank of information. As an example, a combination of wet-weather accidents and low skid numbers at a given location would provide an indication that corrective measures may be necessary for that particular section of pavement.

OPERATIONAL CHARACTERISTICS

Table 18 contains a summary of the operating characteristics of the various friction measuring devices as reported by the states. On the average, between 100 and 150 lane miles of pavement are tested per day with an average of 2 data points obtained per mile.

COSTS

Operating costs, as reported by the individual states, are summarized in Table 19. Also shown in Table 19 are personnel

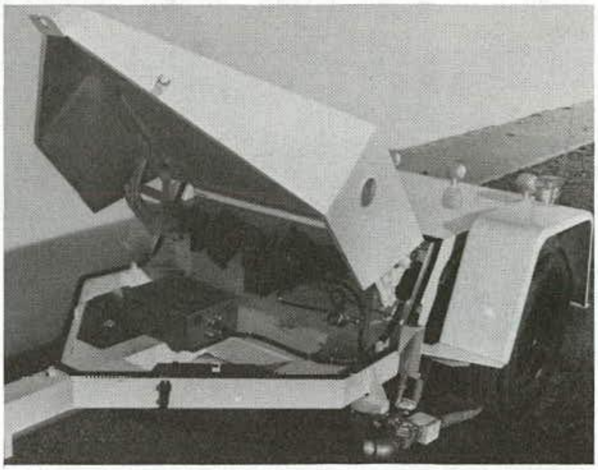


FIGURE 33 Pavement friction tester (K.J. Law model 1270).

FIGURE 32 Locked wheel skid trailer (Cox and Sons Model 9000).

FIGURE 34 "Mu-Meter" of the Utah State Highway Department (*16*).

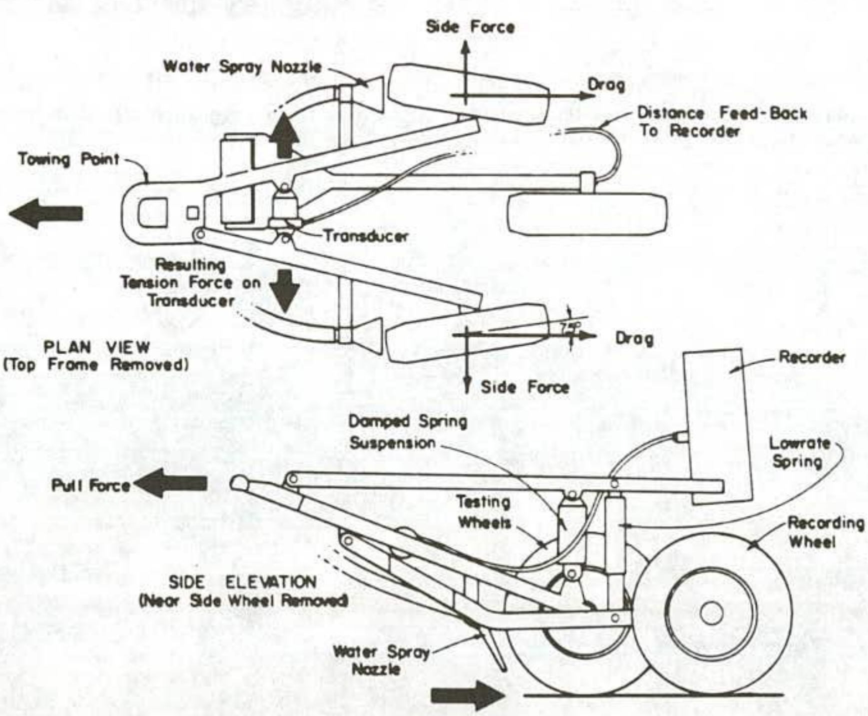


FIGURE 35 Schematic diagram of Mu-meter (*22*).

TABLE 18

OPERATING CHARACTERISTICS OF FRICTION MEASURING EQUIPMENT

Agency	Data Points per Day		Lane Miles of Pavement per Day		Data Points per Mile	Equipment Utilization (days per year)	
	Average	Range	Average	Range		Average	Range
Locked-Wheel Skid Trailer							
Alabama	200		200		5	120	
Arkansas	520		260		2	160	
California	300	200 - 350	200	150 - 300	2	200	
Connecticut	60	5 - 125			3	25	
Delaware	140		70		2	40	
Florida					3		
Georgia	200		100		2	200	
Hawaii	960		240	220 - 260	4	120	
Idaho	150	100 - 300	120	80 - 200	1	100	75 - 150
Illinois						120	80 - 150
Indiana	200	140 - 250	120	100 - 175	1.7	110	90 - 130
Iowa	200		100		2	65	
Kansas	200	200 - 300	70	10 - 100	5	150	100 - 200
Louisiana	50	0 - 100	100	0 - 200	2	140	0 - 250
Maryland	250	25 - 300	120	30 - 200	3	100	80 - 130
Massachusetts	100	50 - 200	50	20 - 100	2	100	70 - 200
Michigan	150	0 - 800	60	0 - 240	3	120	
Minnesota	90		30		3	100	
Missouri	400		80		5	140	
Nebraska			100	75 - 150	2	200	150 - 250
Nevada	150		150		1	90	
New Hampshire						10	
New Jersey	400		80	60 - 100	1	120	
New York	400	200 - 600				100	70 - 135
North Carolina		60 - 90		100 - 150	2		200 - 220
Ohio	236	51 - 499	123	27 - 266	1.9	53	23 - 94
Oklahoma					4	100	
Oregon	100	10 - 150	50	25 - 75	2	100	50 - 150
Pennsylvania	160		16		10	150	
South Carolina	600	300 - 900	200	100 - 300	3	200	150 - 250
South Dakota	175	150 - 200	175	150 - 200	1	95	80 - 105
Tennessee	80		40		2	90	
Texas	750	600 - 840	240	200 - 280	3	60	40 - 80
Virginia	100		33		3	220	195 - 245
Washington	200	100 - 300	200	100 - 300	1	120	60 - 180
West Virginia						180	
Wisconsin	91		45		2	61	
Wyoming	300		150		2	80	
Summary	250	5 - 900	100	10 - 300	2	100	25 - 250
Mu Meter							
Arizona	200		250		1	150	
Idaho	100	50 - 150	160		1	30	
Louisiana	50		100		2	140	
Utah	80	60 - 100	130	100 - 160	1	100	80 - 120
Summary	110	50 - 200	160	100 - 250	1	105	30 - 150

TABLE 19

OPERATING COSTS FOR FRICTION MEASURING EQUIPMENT

	Operating Costs ($)						
	per Data Point		per Lane Mile of Pavement				
Agency	Average	Range	Average	Range	Data Points per Mile	Operating Personnel Required	First Cost
Locked-Wheel Skid Trailer							
Alabama					5		33,800 (1969)
Arkansas	0.89		1.78		2	2	35,000
California	3.00	2.60 - 4.55	4.55	3.00 - 6.00	2	2	
Connecticut					3	2	82,000
Delaware	1.25		2.50		2	2	27,000 (1975)
Florida					3		65,000 (1979)
Georgia					2	1	50,000 (1975)
Hawaii					4	2	65,000
Idaho					1	2	67,500
Indiana	1.10	0.87 - 1.55	1.80	1.25 - 2.16	1.7	2	60,000
Iowa	3.13		6.27		2	2	75,000 (1975)
Kansas	0.20	0.10 - 0.50	1.00	0.50 - 2.00	5	1-2	100,000
Louisiana					2	1	99,960 plus tow
Maryland	0.53		1.06		3	2	91,000 - 114,000
Massachusetts			50.00		2	2	75,000
Michigan					3	2	85,000 plus tow
Minnesota	6.27		20.00		3	2	70,000
Missouri	5.00	4.00 - 10.00	25.00		5	2	85,000 (1980)
Nebraska					2	1-2	75,000
Nevada	2.33	1.55 - 4.66	2.33	1.55 - 4.66	1	2	57,910
New Hampshire			3.75	3.00 - 4.00		2	
New Jersey	2.00		10.00		1	2	100,000
New York	6.00					2	
North Carolina				3.00 - 4.00	2	1	49,687 plus tow
Ohio	5.76		10.95		1.9	2	60,000
Oregon	4.95		9.90		2	2	52,000 (1973)
Pennsylvania	5.00		50.00		10	2	96,000 - 110,000
South Carolina	0.50	0.25 - 1.50	1.50	0.75 - 4.50	3	1	90,000
South Dakota	3.90	3.75 - 4.10	3.90	3.75 - 4.10	1	2	50,000 (1975)
Tennessee	3.38		6.75		2	2	50,000
Texas	0.58	0.38 - 1.75	1.75	1.50 - 2.00	3	2	50,000
Virginia	5.25	5.00 - 6.00	15.00	15.00 - 20.00	3	2	98,500
Washington	1.45	1.25 - 2.50	1.45	1.25 - 2.50	1	2	60,595
West Virginia						2	125,000
Wisconsin	3.40		6.96		2	2	
Wyoming	5.00		10.00		2	2	90,000
Summary	3.35	0.10 - 10.00	11.00	0.50 - 20.00	2	2	50,000 - 125,000
Mu Meter							
Arizona	7.00		7.00		1	1	25,000
Idaho					1	2	60,000
Louisiana					2		99,960 plus tow
Utah	0.90	0.80 - 1.00	0.90	0.80 - 1.00	1		100,000
Summary	4.00	0.80 - 7.00	4.00	0.80 - 7.00	1	1	25,000 - 100,000

requirements. At current prices, it is anticipated that the equipment will cost at least $100,000 including the tow vehicle and the measurements will cost a minimum of about $4.00 per lane mile.

SAFETY FEATURES

Friction measurements are typically made at speeds of 40 miles per hour (64 km/h) and hence require little traffic control. Rotary lights, flashing signs, or strobe lights are typically used on the tow vehicle and/or trailer. Police protection is normally required if friction measurements are to be made at intersections.

MAINTENANCE REQUIREMENTS

Mechanical and electonic repair are frequently needed to keep friction testing trailers in operation. Brake pads, water pump, wheel bearings, tires, transducers, and various electrical components require maintenance. Costs are typically $2000 to $5000 annually. Calibration charges are about $10,000.

EQUIPMENT DEVELOPMENTS

Few new mechanical designs have been introduced for friction measuring trailers. Computer hardware and software improvements have followed developments in the electronic industry.

CHAPTER FIVE

ROUGHNESS MEASURING EQUIPMENT

Ride quality is generally related to the roughness of the pavement structure. Road roughness can, in turn, be defined as "the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic pavement loads, and pavement drainage" (*23*). Other definitions are possible; for example, roughness may also be defined as "the distortion of the road surface that contributes to an undesirable, unsafe, uneconomical, or uncomfortable ride" or "the distortion of the road surface that imparts undesirable vertical accelerations and forces to the vehicle or to its riders and thus contributes to an undesirable, uneconomical, unsafe, or uncomfortable ride" (*24*).

Road roughness is measured by two types of equipment, that which measures the response to roughness (response-type equipment) and that which measures actual profiles (profilometers). To a "reasonable" degree, the profiling methods provide accurate, scaled reproductions of the pavement profile along a straight line. It must be recognized, of course, that the range and resolution of any of the profiling devices are limited.

RESPONSE-TYPE EQUIPMENT

The response-type equipment records the dynamic response of mechanical systems traveling on the road surface at some predetermined constant speed. Accordingly, a relative measurement of roughness is obtained that depends on the characteristics of the mechanical system and the speed of travel.

Equipment of this type includes: (a) BPR Roughmeter, (b) PCA Road Meter, (c) Mays Meter, (d) Vetasmic Roadmeter (Cox), (e) Automated Pavement Response Roughness Test System (New York), (f) TRRL Bump Integrator, and (g) NAASRA (Australia) Roughness Meter. Data on equipment commonly used in the United States is given in Table 20.

The BPR Roughometer is a single-wheel trailer that measures the undirectional vertical movements of a damped leaf-sprung wheel by a mechanical integrator as the trailer is towed along the roadway (Figure 36) (*25*) (data expressed as inches per mile). Because of the slow response of the electromechanical counter, measurements are usually made at 20 mph (32 km/h). Modifications have been made to the device to improve data acquisition capabilities and to permit operations at higher speeds (*25–27*). The Bump Integrator of the TRRL is a modified version of the BPR Roughometer.

Road meters comprise a widely used type of response equipment. HRB Special Report 133 (*28*) contains an extensive discussion of the performance and capabilities of this type of equipment. These meters measure the vertical movements of the rear axle of an automobile relative to the vehicle frame (Figure 37). In the United States, commonly used types are the Portland Cement Association (PCA) Meter (Figure 38), the Cox and

TABLE 20

USES OF ROUGHNESS MEASURING EQUIPMENT

Equipment	No. of States Using	Use of Equipment: Network Management Yes	Network Management Sometimes	Project Management Yes	Project Management Sometimes	Other Uses
BPR-type roughometer	4	1	-	1	1	Research
Mays ridemeter	22	11	7	14	6	Planning; research
Ultrasonic roadmeter	5	5	-	3	-	Research
PCA-type roadmeter	5	5	-	1	1	Research; smoothness quality
Profilograph	4	1	1	2	1	Research; smoothness quality
Profilometer	3	1	-	2	-	Research
Surface dynamics profilometer	5	1	2	3	-	Research; source of pavement roughness; correlate Mays meter

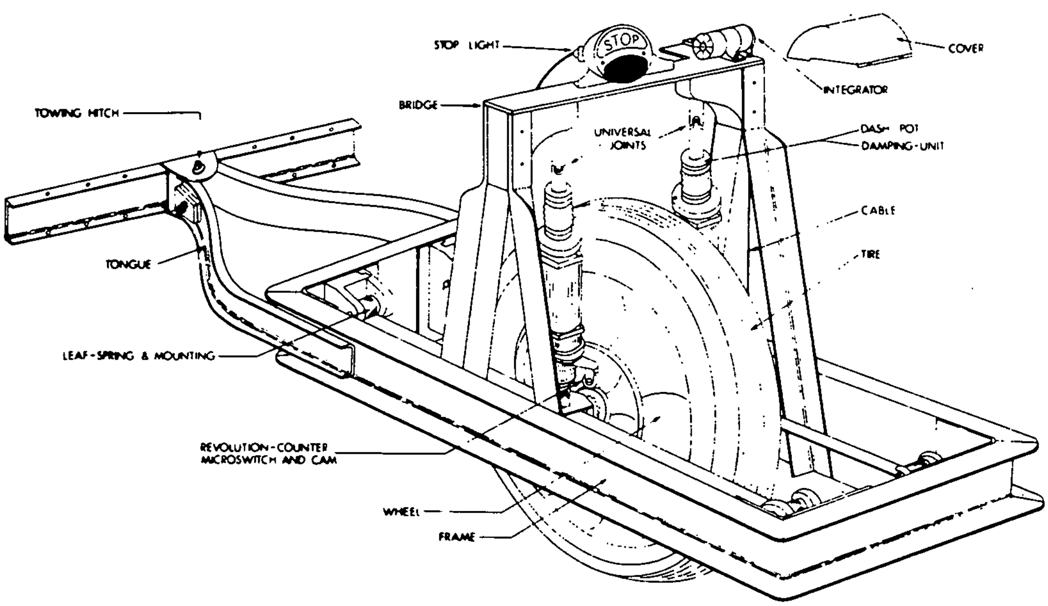


FIGURE 36 RPR Roughmeter (*25*).

Sons Meter and the Mays Meter (Figure 39). The NAASRA Roughness Meter (*29*) used in Australia is a modified version of this type of equipment.

This type of equipment has the significant disadvantage that it must be calibrated frequently to ensure that reasonable and reproducible measurements are obtained. The road meter instruments exhibit hysteresis and quantization effects (*30*) (which can be eliminated). The vehicles in which meters are installed contribute many potential sources of variation including: variations in vehicle suspension (springs and shock absorbers), vehicle weight changes, and tire pressure and tire/wheel nonuniformities (*23, 30*).

Although all road meters measure a dynamic effect of roughness, this type of measurement does not define the profile of roughness. Some wavelengths will be attenuated and others amplified, depending on the mechanical system (*23*). However, road meters are useful for rapid evaluation to predict the user's response to ride quality. If more detailed information on the actual profile is required, then it is necessary to use another form of equipment capable of measuring the profile.

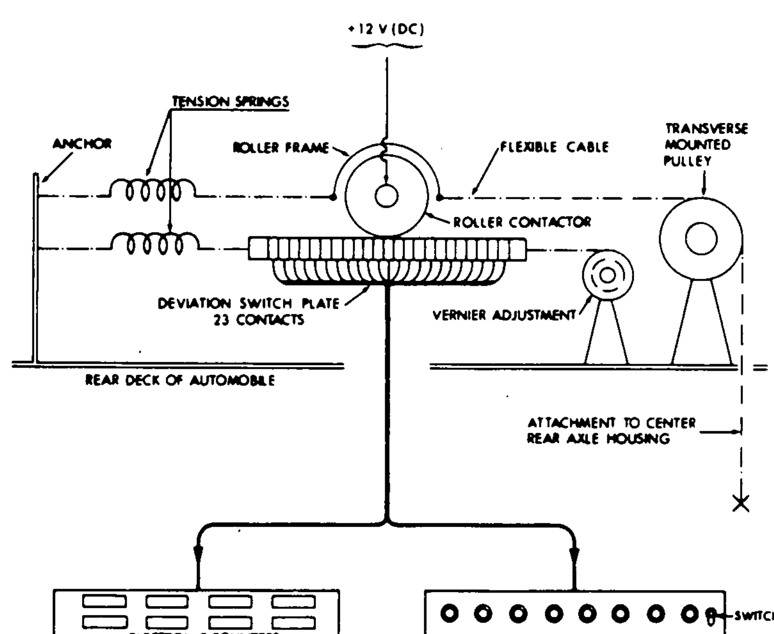


FIGURE 37 PCA Road Meter (*25*).

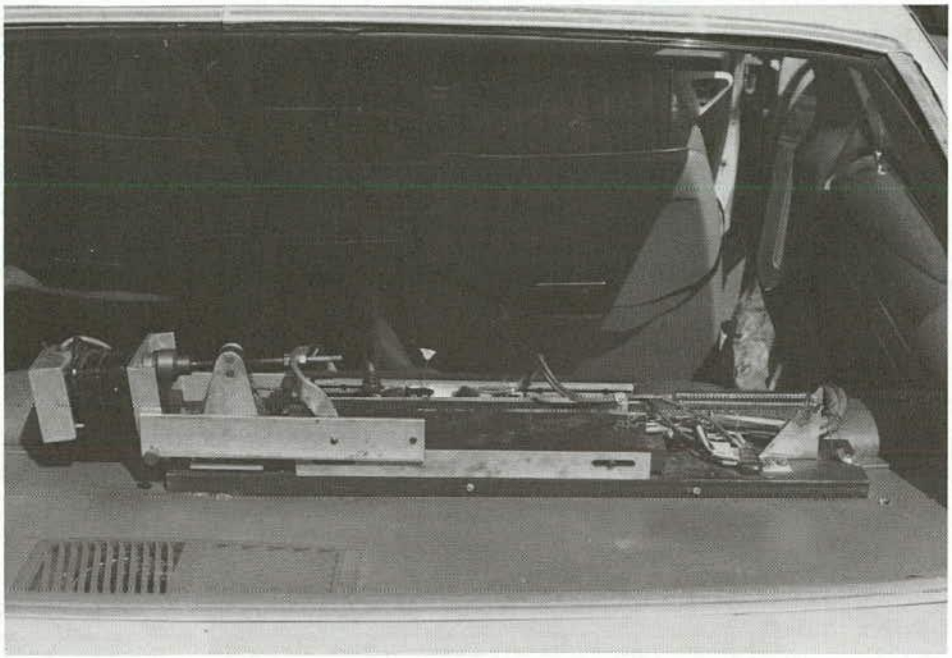


FIGURE 38 Looking into rear deck from outside of passenger vehicle (Shop made PCA Roadmeter).

PROFILING EQUIPMENT

Profiling equipment (or profilometers) can provide complete information about the pavement profile, within the limits of the particular device. Included are:

1. Straight edges, including wheel-mounted devices, (Figure 40). These devices have spans up to 30 feet (9 m) (*31*). The equipment is operated statically or at very low speeds; it is not suitable for profiling because it cannot measure wavelengths that are harmonics of its span (e.g., 1/4, 1/2, etc.) (*23*).

2. The CHLOE profilometer (*32*) (Figure 41) measures the slope of the road profile at regular intervals from which the slope variance is calculated. The slope is the change in angle between two reference lines, one of which is defined by the two small wheels and the other by the 20 ft (6 m) long frame. The equipment operates at a speed of about 2 mph (3 km/h) to minimize dynamic effects. Inaccuracies are introduced for wavelengths shorter than the distance between the two wheels and information is not provided for longer wavelengths.

3. Laser profilometer (*33*) (U.S. Air Force) consists of a horizontal laser beam, which serves as a reference, and a tracking

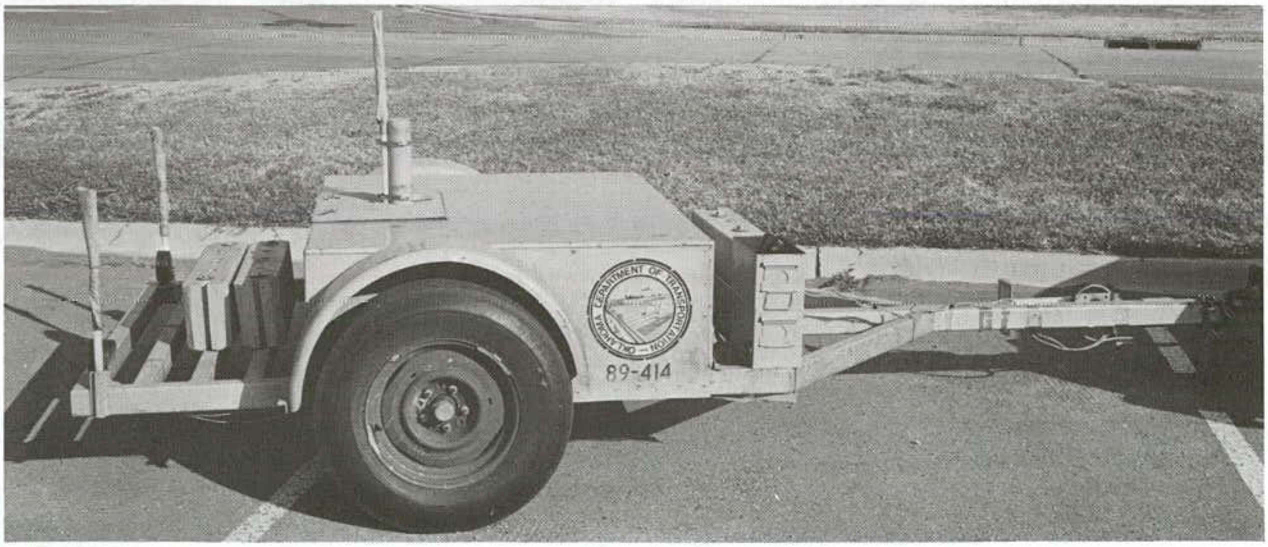
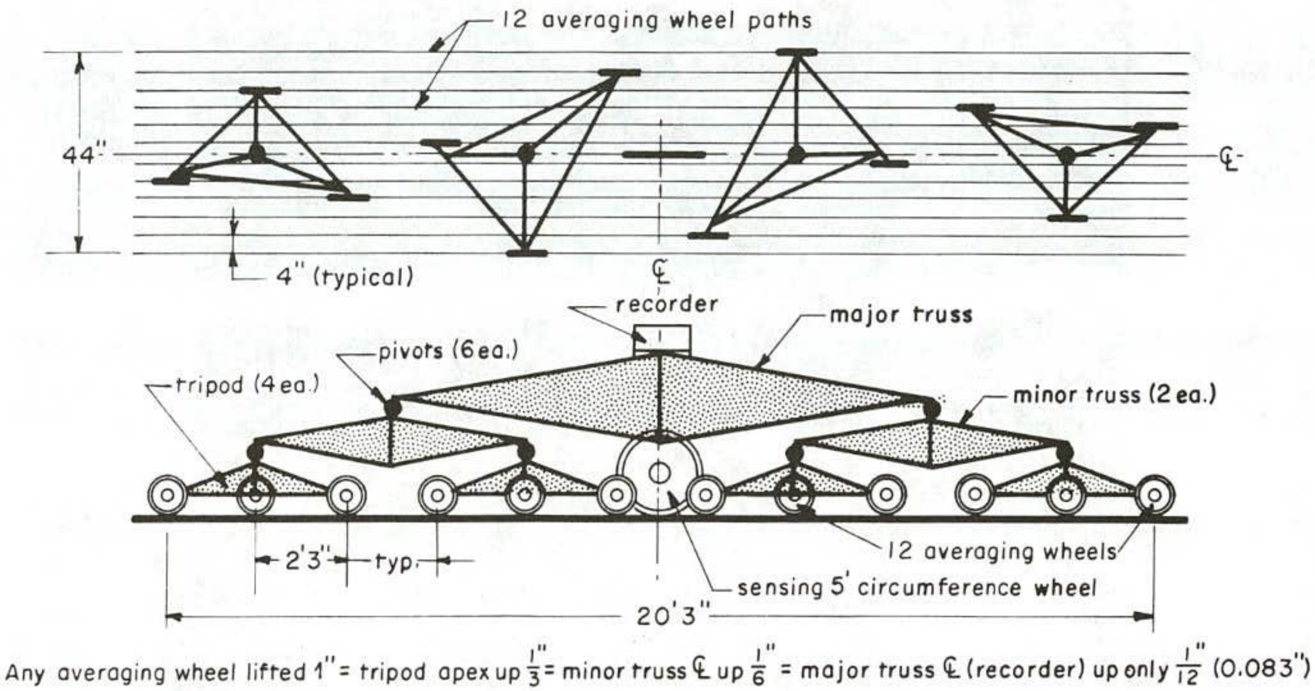
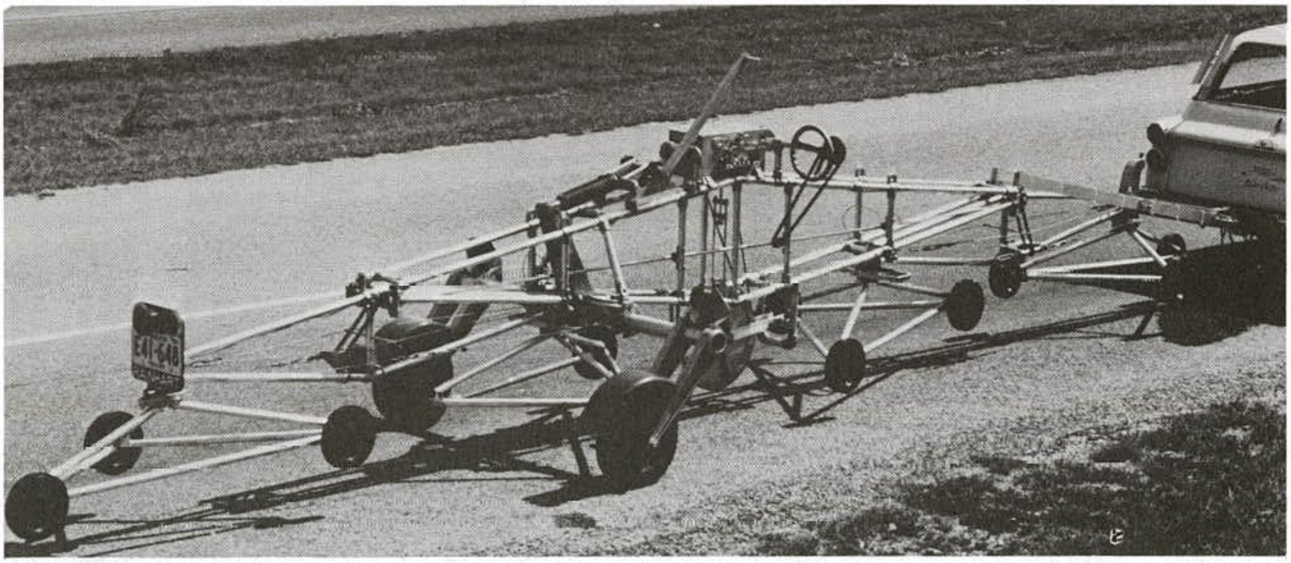


FIGURE 39 Mays Ride Meter trailer unit.



(a)



(b)

FIGURE 40 Schematic diagram (a) and photograph (b) of longitudinal profilograph (Rainhart Model 86V).

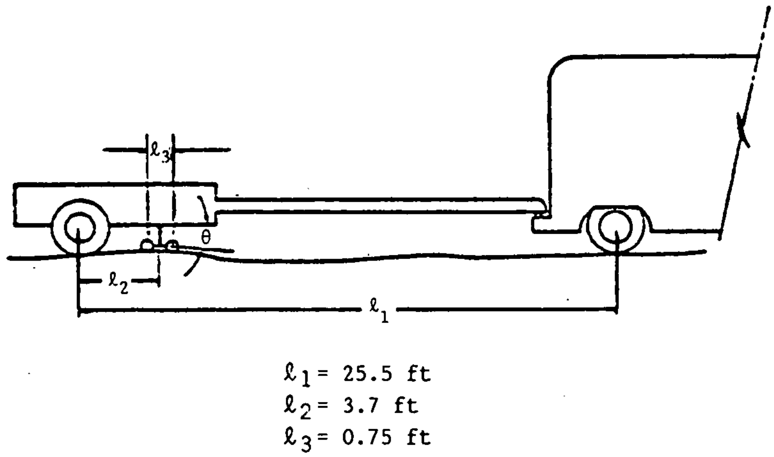


FIGURE 41 Schematic representation of CHLOE profilometer.

vehicle that moves slowly [3 mph (5 km/h)] along the runway measuring the profile. Profiles of wavelengths up to about 400 ft (120 m) are measured.

4. Surface Dynamics Profilometer (also called General Motors Research Profilometer, General Motors Profilometer, and Rapid Travel Profilometer) (*34*) (Figure 42) uses two spring-loaded, road-following wheels, instrumented with a linear potentiometer to measure relative displacements between the vehicle frame and the road surface. Accelerometers, mounted on the frame over each of the following wheels, are used to measure the vehicle frame motion by double integration of the signal. The frame motion is then added to the relative displacements motion to yield (with additional processing) the road profiles of the wheel paths. By using a road-wheel displacement signal plus the double integration of the body accelerations, greater accuracy is obtained in measurement of long wavelengths. With this equipment, frequencies below 1 Hz are measured primarily by the accelerometers and those above 2 Hz are measured primarily by the linear potentiometer. Today the primary disadvantage of this system is its cost, since new data processing equipment has reduced the necessity for highly skilled operators, which the earlier model required.

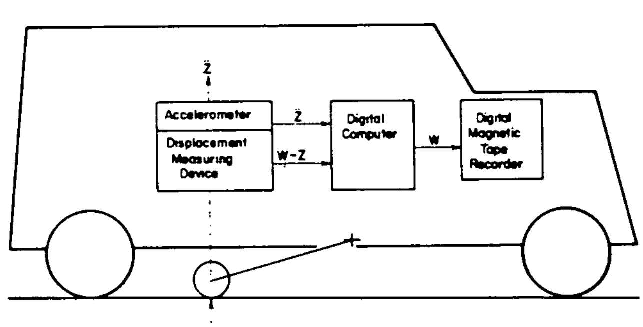


FIGURE 42 Surface dynamics profilometer (*23*).

A summary of theoretical differences between the Surface Dynamics Profilometer, APL, CHLOE, rolling straight edges, and the BPR Roughometer is presented in Figure 43 (*23*). The APL device, developed in France, is shown in Figure 44. The PCA and Mays Meters have responses similar to the BPR Roughometer response shown in Figure 43.

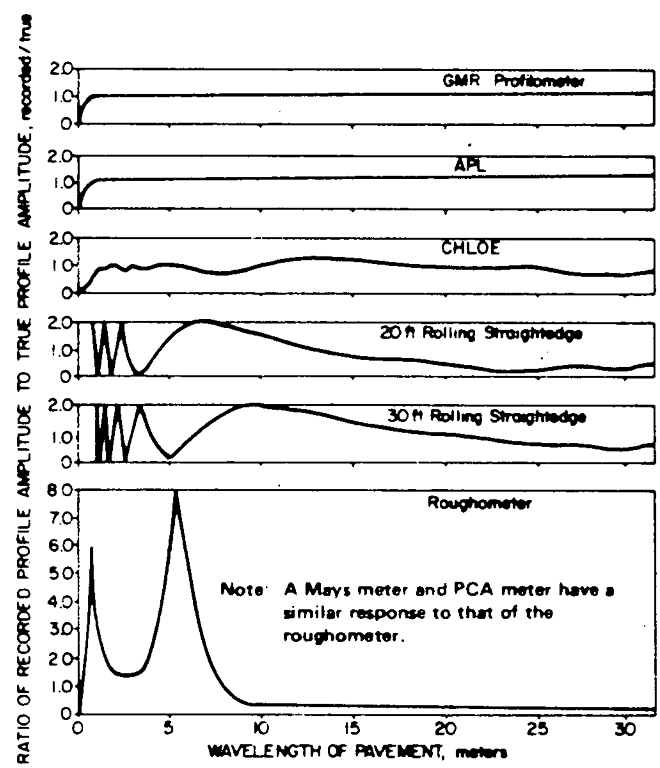


FIGURE 43 Theoretical difference between GMC Profilometer, APL, CHLOE, Rolling Straightedges, and BPR Roughometer (*23*).

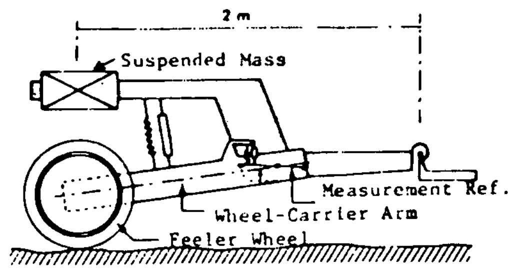


FIGURE 44 LCPC (APL) profilometer (*23*).

APPLICATION AND DATA USE

Table 20 contains a summary of the uses of roughness measuring equipment. It will be noted that these measurements play a significant role in the development of data at the network-level pavement management and that car ride meters predominate in obtaining the roughness data.

In developing roughness data, it is important to emphasize that the response-type equipment must be *calibrated* regularly because the equipment is subject to changes that can lead in turn to inconsistent measurements.

Profilometers, for which dynamic effects are negligible, can be calibrated directly on surfaces for which the absolute profile has been obtained. The surface dynamics profilometer equipment can be calibrated by bouncing the profilometer in a stationary position (*23*).

Calibration of the response-type equipment is more difficult. Gillespie et al. (*30*) have proposed standard calibration procedures, one of which makes use of the surface dynamics profilometer equipment. In this method, the profilometer is used to measure a profile, which is then used as input to a simulation of a response-type device. The output of the simulation is then the output that would be expected from a response-type device driven in that profile. This procedure must be done for a range in roughnesses since the output of the response-type device is a function of roughness (*23*). Actual pavements or test track pavements can be used.

Response-type equipment provides a single measure of roughness, which because of ease of obtaining (at comparatively low cost) has been and will continue to be a useful statistic in the pavement management process. It does not, however, provide a measure of the actual road profile.

With the road profile, it is possible to develop other measures of roughness that may be useful in evaluating the effects of the profile on the vehicle and the driver including harmonic analysis, power spectral density, and amplitude-frequency distribution (*23*). Such approaches are still, however, in the research phase.

NCHRP Report 275 (*35*) indicates that subjective appraisals of pavement ride quality can be computed from physical measurements of that portion of the pavement's profile between 10 and 50 Hz. NCHRP Project 1-23(2) is currently under way to determine the suitability of the method for adoption by AASHTO as a universal method for determining pavement rideability.

For the near term, single measures of roughness and their correlations with performance such as the Present Serviceability Index will be used in pavement management systems.

OPERATIONAL CHARACTERISTICS

Operating characteristics of the roughness measuring equipment, as implemented by the states, is summarized in Table 21. With car ride meters approximately 200 lane miles can be evaluated daily.

COSTS

Operating and initial costs for the individual states are summarized in Table 22. It is interesting to note that the cost of car ride meters is of the order of $15,000 (including the car) whereas profilometers, which provide a measure of the true profile, cost approximately 15 times as much.

Personnel requirements, as noted in Table 22, are the same regardless of the type of equipment used.

SAFETY FEATURES

Roughness measurements are typically made at near traffic operating speeds. Rotary lights, flashing signs, and strobe lights are typically used on the vehicle and/or trailers.

MAINTENANCE REQUIREMENTS

Mechanical and electrical repair is needed to keep the roughness equipment in operation. Shock absorbers, tires, wheel bearings, and various electrical components require maintenance. Costs are typically in the range of $100 to $300 annually.

EQUIPMENT DEVELOPMENTS

Several items of noncontact equipment have been developed in the last several years to measure surface roughness. This equipment makes use of incandescent light, ultrasound, or laser light in combination with microprocessors to measure road roughness.

The K. J. Law Engineers Model 690DNC is a noncontact road profilometer that measures and records the road surface profile in each of the vehicle's two wheel paths. An optical displacement measuring system based on reflectivity from the road surface and an accelerometer are used in each wheel path. Measurements can be made between 10 and 55 miles per hour (16 and 90 km/h) (Figure 45).

The Model 8300 K. J. Law Engineers noncontact roughness measuring devices use ultrasonic sensors to measure displacement. The equipment can also be used to develop rating condition logs and rut depth measurements (Figure 46).

Equipment developed by Dynatest Consulting; Novak, Dempsey and Associates; PASCO Corporation; and Highway Products International to measure pavement roughness has been previously discussed. Ultrasonic sensors, laser technology, and accelerometers are used with microprocessors to determine pavement roughness.

Cox and Sons produces a roughness device using an ultrasonic noncontact probe. MAP, S.A. markets a longitudinal profile analyzer developed in France (Figure 47). The Transportation and Road Research Laboratory concept of using laser equipment is shown in Figure 48.

TABLE 21

OPERATING CHARACTERISTICS OF ROUGHNESS MEASURING EQUIPMENT

Agency	Data Points per Day		Lane Miles of Pavement per Day		Data Points per Mile	Equipment Utilization (days per year)	
	Average	Range	Average	Range		Average	Range
BPR-type Roughmeter							
Alabama			150			160	
Missouri	40,000		4		10,000	10	
Summary	40,000		100		10,000	80	
Mays Ridemeter							
Alaska			400			15	
Arizona			200			60	
Arkansas			260	195 - 360		200	
Kansas	3,000		300	250 - 325	10	100	
Louisiana	100		20	5 - 100	5	100	
Maryland			100	10 - 200		120	60 - 180
Massachusetts			50	20 - 100		100	70 - 200
New Hampshire						30	
New Jersey	2,000	1,600 - 2,400	100	80 - 120	20	120	
Ohio			150	100 - 200	5		
Oklahoma			200		4	15	10 - 20
Pennsylvania	500	150 - 1,500	50		10	150	
South Carolina			200	100 - 300		125	1[illegible] - 150
Tennessee			10			50	
Texas			200	160 - 200		75	50 - 100
Virginia			30			80	
West Virginia					6	50	
Wyoming	250		250		1	80	
Summary	1,000	150 - 2,400	140	5 - 360	10	80	10 - 300
Ultrasonic Road Meter							
Idaho			200	150 - 300	2	100	
Indiana	150	100 - 200	150	100 - 200	1	100	90 - 130
Nevada	225	150 - 300	225	150 - 300	1	35	65 - 105
Utah	250	200 - 300	250	200 - 300	1	150	125 - 175
Washington	300	200 - 350	300	200 - 350	1	65	40 - 90
Summary	230	100 - 350	225	100 - 350	1	100	40 - 175
PCA Road Meter							
Iowa	30		150		5	110	
Minnesota						20	
Nebraska	200	100 - 300	200	100 - 300	1	200	100 - 300
Oregon	135	100 - 150	135	100 - 150	1	110	100 - 120
Wisconsin	240		240		1	110	
Summary	150	30 - 300	180	100 - 300	1	110	20 - 300
Profilograph							
California	150		150		1	240	
Louisiana	20		10		2	30	
Summary	80		80		1	130	
Profilometer							
Missouri	40,000		4		10,000	10	
South Dakota	1,000,000		200		5,280	50	
Summary	500,000		100		7,000	30	
Surface Dynamics Profilometer							
Michigan			50		1,572	150	
Ohio			80	20 - 100		180	
Texas			10	5 - 15		50	
West Virginia						100	
Summary			45	5 - 100		120	25 - 150

TABLE 22

OPERATING COSTS FOR MEASURING EQUIPMENT

	Operating Costs ($)						
	per Data Point		per Lane Mile of Pavement				
Agency	Average	Range	Average	Range	Data Points per Mile	Operating Personnel Required	First Cost
BPR-type Roughmeter							
Alabama						2	43,700 (1982)
Missouri			150.00		10,000	5	6,000 (1964)
Summary						2	45,000
Mays Ridemeter							
Alaska						2	12,000
Arizona	4.00		4.00			2	5,000
Arkansas			0.85			1	
Georgia							6,200
Kansas	0.35		3.50		10	2	7,846 plus tow
Louisiana	1.38		6.91		5	2	8,000
Massachusetts			15.00			2	17,000
New Hampshire			10.00			3	3,000 plus car
New Jersey					20	2	25,000
Ohio			7.00	6.00 - 9.00	5	2	1,500 plus car
Oklahoma						2	1,100 plus car (1971)
Pennsylvania			8.00		10	2	20,000
South Carolina			0.75	0.60 - 1.50		2	18,000
Tennessee			0.21			1	7,000
Texas	0.18		0.93	0.87 - 0.97			10,000
Vermont	1.75		1.75		20	2	1,060 plus car
Virginia			6.00	2.00 10.00		1	2,000 plus car
West Virginia			1.00		6	1	1,074 - 1,663
Wyoming	1.50						
Summary						2	2,000
Ultrasonic Road Meter							
Idaho	3.00		3.00		2	2	60,000
Indiana	0.67	0.50 - 1.00	0.67	0.50 - 1.00	1	1	14,200
Nevada	1.04	0.78 - 1.56	1.04	0.78 - 1.56	1	2	7,800 plus car
Utah	0.60	0.40 - 0.80	0.60	0.40 - 0.80	1	2	10,000 plus car
Washington	0.95	0.76 - 1.26	0.95	0.76 - 1.26	1	2	8,500
Summary	1.25	0.40 - 3.00	1.25	0.40 - 3.00	1	2	8,500 plus car
PCA-type Road Meter							
Iowa	26.00		5.20		5	2	1,200 (1975)
Minnesota						2	500
Oregon	1.65		1.65		1	2	
Wisconsin	2.00		2.00		1	2	
Summary	2.00		2.00		1	2	1,200
Profilograph							
California	4.00				1	1	13,600
Louisiana	9.90		19.80		2	3	8,270
Summary	7.00		19.80		1	2	12,000
Profilometer							
Missouri			150.00		10,000	5	6,000 (1984)
South Dakota			2.00		5,280	2	30,000
Summary							6,000
Surface Dynamics Profilometer							
Ohio			8.00			2	200,000
Texas			2.00	1.50 - 2.50		2	216,000
West Virginia			1.12			2	200,000
Summary			4.50			2	225,000

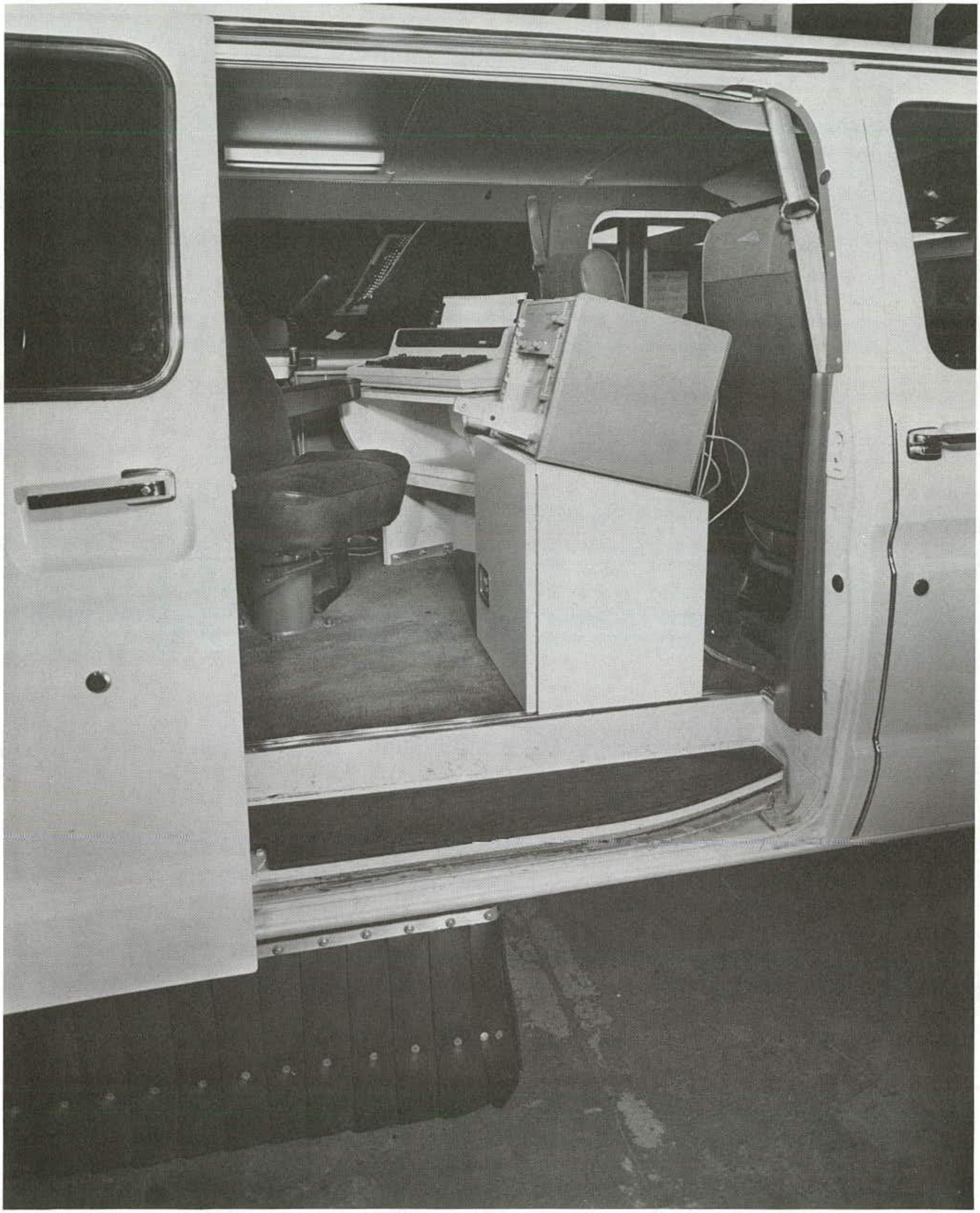


FIGURE 45 Operator terminal chart recorder and noncontact shroud is mounted in Surface Dynamics Profilometer (K.J. Law Model 673) (The Fleury Studios, Inc.).

FIGURE 46 Ultrasonic displacement measurement cannister mounted on roughness measuring vehicle (K.J. Law Model 830V).

FIGURE 47 Longitudinal profile analyser (APL 25) (MAP, S.A.).

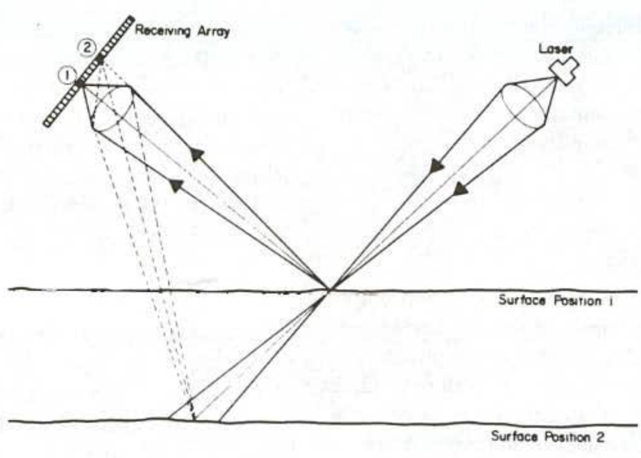


FIGURE 48 Basic contactless displacement transducer design (*23*).

CHAPTER SIX

TRAFFIC VOLUME AND WEIGHT MEASURING EQUIPMENT

Traffic volume and traffic weight distribution data are necessary input to pavement management systems, statewide transportation studies, traffic control studies, pavement thickness design, pavement overlay design, etc. In addition, the Federal Highway Administration requires these types of data from the states.

Equipment for collecting traffic volume and traffic weight data includes portable counters, fixed counters, weigh-in-motion devices, portable scales, and permanent weigh stations. Portable and fixed counters are capable of determining the number and types of vehicles. Vehicle weights and axle load distributions are obtained from weigh-in-motion devices, portable scales, and permanent weigh stations.

Information on equipment for collecting traffic volume and weight data is contained in several other syntheses. Synthesis 130 (*36*) contains information on various types of traffic counters and classifiers. Information on weigh-in-motion devices can be found in Synthesis 124 (*37*), which covers all types of equipment used by state agencies to weigh trucks in motion. Syntheses 68 (*38*) and 82 (*39*) give information on the use of portable scales and permanent weigh stations.

TRAFFIC COUNTERS

Traffic counting equipment in current use includes simple totalizing counters, punched paper tape counters, punched paper tape counters with classifiers, solid state to cassette tape counters with classifiers, microprocessor-based counters with solid state recording memory and transfer. These counters may be portable or fixed and can use air tubes, electric eyes, magnetometers, or inductance loops to obtain data (*36*).

WEIGH-IN-MOTION EQUIPMENT

Weigh-in-motion equipment can be located in a pavement or on a bridge. These systems allow several hundred trucks per hour to be weighed. One- or two-person crews are generally required; some installations operate automatically, with or without telemetry systems. Permanently installed systems that require no set-up time are used by some states. Other types of systems are portable or semiportable and require 15 minutes to 1 hour of set-up time.

In pavements, the equipment is placed directly in the highway lane and does not interfere with the movement of traffic. However, the weigh-in-motion scales should be located away from areas of vehicle acceleration or deceleration and should not be located where the pavement is poor. Accuracy is affected by vehicle speed and the roughness of the approach.

Bridge weighing systems are installed on bridges that have been calibrated for the instrumentation. Readings are somewhat affected by vehicle speed, but speed effects can be accounted for and acceptable readings obtained.

Both systems cost substantially more than portable scales; and personnel required for maintaining the systems require considerable training. Calibration of weigh-in-motion scales should be performed with the use of a permanent weigh station. The Federal Highway Administration has developed calibration guidelines.

PORTABLE SCALES

Portable scales have been used by a number of states for truck weight studies and enforcement purposes. Usually accurate weights can be obtained. Many types of scales are easily set up and quickly removed. However, the survey cannot be easily conducted in an active traffic lane, only 25 to 35 trucks per hour can be weighed, five to six crew members are required, and the operation is potentially unsafe on urban roadways and in bad weather.

PERMANENT WEIGH STATIONS

Permanent weigh stations are usually located on Interstate highways and other major truck routes. Typical locations include ports of entry and sites where there is a low chance of bypass. The stations use single or triple platform scales (either beam or electronic). Permanent weigh stations may be operated continuously 24 hours per day or for short periods (typically 2 to 4 hours) at random times. Although useful for enforcement purposes (especially when combined with the use of portable scales on bypass routes), data obtained from permanent weigh stations may not be representative of actual truck weights and therefore would not be adequate for planning and design purposes.

APPLICATION AND DATA USE

Traffic volume and traffic weight data are important information for use in project management studies. The selection of rehabilitation alternatives is based on the need to carry existing and future traffic (in terms of equivalent axle loads) for the design life of the pavement. Traffic volume considerations may also dictate the need for lane and/or shoulder widening.

Traffic volume and traffic weight are important parameters used to establish roadway section priorities in network management systems. Optimization techniques associated with network management systems sometimes make use of benefit-cost analyses, which are dependent in part on traffic volumes.

COSTS

First costs for portable traffic counters are in the range of $100 to $1000 dollars depending on the type of recording equipment utilized. Fixed traffic counters have first costs that range from about $1000 to $5000 depending on the degree of automation of the detector, summator, and recorder utilized.

Typical first costs for weigh-in-motion equipment is $100,000.

SAFETY FEATURES

Fixed and portable traffic counters and classifiers require no traffic control except for installation when conventional signing and lane closures may be required depending on traffic volumes. Permanent recording equipment should be located so that it does not present a hazard to traffic.

Portable scales require cones, signs, a flagman, stop-go lights, and perhaps police to operate. Portable scales are almost impossible to use on high traffic volume facilities. Permanent weigh stations are designed such that truck traffic can easily pull off and on to travel lanes. Usually no additional safety procedures are needed.

Portable weigh-in-motion equipment must be set up and normal precautions must be taken. Fixed weigh-in-motion equipment has no safety problem when installed. Portable recording equipment for weigh-in-motion equipment should be located at a safe distance from travel lanes.

MAINTENANCE REQUIREMENTS

Annual maintenance costs for fixed and portable traffic counters are reported to be less than $100. Higher maintenance costs can be expected with the addition of on-site automated equipment.

Louisiana reports annual maintenance costs of about $12,000 for weigh-in-motion devices. Little maintenance cost data has been reported.

Annual maintenance costs for portable and fixed scales are in the order of $500 to $1000 as reported in Oregon and South Carolina.

EQUIPMENT DEVELOPMENTS

Automated data collection, storage, and transmission systems continue to be developed by the industry. Improvements in weigh-in-motion equipment can be expected. Problems with road roughness, traffic speed and electrical systems need to be solved. Considerable improvements need to be made in bridge weigh-in-motion systems. These problems are associated with data scatter and collection of data under heavy traffic conditions.

CHAPTER SEVEN

CONCLUSIONS AND RESEARCH NEEDS

CONCLUSIONS

Pavement Management Systems

A number of states and local governmental agencies have or are in the process of developing pavement management systems. Through the use of these systems, administrators and engineers are able to effectively allocate funds for the reconstruction, rehabilitation, and maintenance of the roadway network. Network-level and project-level management systems have been developed. At the network level, decisions are made primarily for groups of projects or an entire highway or street network. The project-level management systems are concerned with more technical management decisions for individual projects. Key activities of pavement management systems include:

1. Roadway section identification
2. Pavement condition surveys
3. Collection of data to define
   a. Design and construction
   b. Maintenance history
   c. Rehabilitation history
   d. Drainage
   e. Geometrics
   f. Traffic volumes and weights
4. Identification of maintenance and rehabilitation alternatives
5. Development of performance prediction models
6. Network programming
7. Optimization
8. Data management
9. Report preparation

One of the major problems in developing a pavement management system is the tendency to collect more data than is necessary or useful for the system. Because of cost considerations, care should be taken not to collect more information than is necessary to support the system. Experience has indicated that major data collection efforts for operating pavement management systems are required to define pavement condition and traffic. Hence, this synthesis is associated with describing equipment that can be used to define structural capacity, surface distress, friction, roughness, traffic volume, and traffic weight.

Simple network pavement management systems have been developed that collect only pavement surface distress information. Simple project pavement management systems utilize pavement surface distress and a measure of traffic weight and volume. At present, several large state-of-the-art network pavement management systems utilize pavement surface distress, friction, roughness, traffic volume, and traffic weight measurement information. These state-of-the-art systems do not usually include structural capacity measurements. Rather, such measurements are used in project management systems.

Equipment Considerations

Desirable features for equipment suitable for collecting data for pavement management systems include:

1. Low first costs
2. Low operating costs (cost per data point or lane mile)
3. Low maintenance costs
4. Accurate
5. Self-calibrating
6. Safe to operate under heavy traffic conditions
7. Operate by technical-level personnel
8. Operate in all types of environmental conditions
9. Collected data easily transferred to main frame, micro- or mini-computer
10. Measure more than one desirable set of data at the same time

With these desirable features in mind, several equipment manufacturers have developed relatively high-speed computer-oriented equipment. The first cost of this equipment is high but costs per data point or lane mile (operating costs) are expected to be low. Unfortunately, this type of equipment will require highly trained personnel.

Equipment to Measure Structural Capacity

This equipment will be used primarily at the project-management level. The Benkelman beam and Dynaflect are most commonly used. The falling-weight deflectometers are preferred as they can load pavements at actual traffic loads, account for stress dependency of materials, and dynamically load a pavement. Equipment needs to be developed that can be operated at creep or highway speeds. The California Traveling Deflectometer is the type of equipment desired from a speed of operation point of view.

Equipment to Measure Surface Distress

This equipment can be used at both the network and project management levels. Most surface distress measurements are made visually by two-person crews and recorded on data input forms. Automated recording equipment should be utilized if possible to speed the data entry process. Photologging equipment has improved over the years, but the digitizing process is extremely time-consuming. Systems based on laser and video imaging processing technology need additional research and development. Equipment other than photologging needs to be developed that can be operated at creep or highway speeds. Laser and image processing offers hope for this type of equipment.

Equipment to Measure Friction

This equipment can be used at both network and project management level. The greatest use is at the project level. The locked-wheel skid trailer is most commonly used. Existing equipment appears to be suitable. Data processing capabilities have been greatly improved over that associated with the older friction measuring equipment. Methods to safely measure friction at intersections are needed.

Equipment to Measure Roughness

This equipment can be used at both the network and project management levels. Most state pavement management systems use the equipment at the network level. Most local government agencies do not use roughness equipment. The Mays Ride Meter is the most commonly used device. Ride meters are relatively inexpensive and operate at highway speeds. These devices are not as accurate as profilometers. The higher cost and more accurate profilometers will probably initially be used to calibrate the ride meters. Data processing capabilities for ride meters have been greatly improved over the last several years. Noncontact equipment using incandescent light, ultrasound, and laser technology is currently being used by a few agencies.

Equipment for Measuring Traffic Volume and Traffic Weight

Traffic volume and weight measurements are routinely made for purposes other than pavement management systems. These data are probably most useful at the project level although some network-level systems make use of the data. The equipment for traffic volume and traffic weight has been in use for a number of years. The most recent improvements are associated with data storage and transmissions to central computer facilities. Improved weigh-in-motion systems are needed.

RESEARCH NEEDS

1. Equipment development needs to proceed in order that the cost (per data or lane mile) for data collection and transfer to central computer facilities can be reduced.
2. New equipment development must consider first costs, operators technical requirements, maintenance requirements, and safety.
3. Equipment that operates at traffic speeds needs to be developed for structural capacity and surface distress measurements.
4. Equipment standardization and calibration procedures need to be developed for structural evaluation, surface distress, roughness, and traffic load measuring equipment. The techniques used for friction trailer calibration should be considered.

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APPENDIX A

SURVEY OF PRACTICE

NCHRP Project 20-5
Topic 15-04

"Equipment for Obtaining Pavement Condition and Traffic Loading Data"

Scope

One of the most important elements of systematic pavement management is the collection of adequate pavement condition and traffic loading data. Considerable information exists concerning the types of data that are being collected; however, there are questions on what equipment is available for measuring, recording, and storing these data. This synthesis will address the advantages, disadvantages, costs, and data collection techniques of equipment used for obtaining data on friction, surface distress, ride/profile, traffic/loading, and structural properties.

Individual Responding to Survey

Name: ______________________________

Title: ______________________________

Address: ______________________________

____

Phone Number: ______________________________

Please return reply by July 29, 1983 to:

Jon A. Epps
Department of Civil Engineering
University of Nevada-Reno
Reno, Nevada 89557
(702) 784-6873

A. Please list the name, type, and manufacturer of the items of equipment that are used for obtaining specific pavement information in your state. Typical equipment has been identified for reference purposes. More than one item of equipment can be listed for each type of data collected.

Type of Data Collected	Typical Equipment	Name, Type, and Manufacturer of Equipment
Structural Capacity	Dynaflect	
	Benkelman Beam	
	Road Rater	
	Falling Weight Deflectometer	
	Other	
Surface Distress	Visual Condition Form	
	Photo Equipment	
	Other	
Friction	ASTM Locked Wheel Skid Trailer	
	Mu Meter	
	Other	
Roughness	Mays Meter	
	PCA Meter	
	Cox Meter	
	Surface Dynamics Profilometer	
	Other	
Traffic Volume and Weight	Portable Counters	
	Fixed Counters	
	Weigh in Motion	
	Portable Scales	
	Permanent Weigh Station	
	Other	

B. Please provide detailed information to define uses, operational characteristics, and costs of the equipment.

1. Equipment ____

2. Uses of Equipment

   a. Input to network management system   Yes_____ No_____ Sometimes_____

   b. Input to project management system   Yes_____ No_____ Sometimes _____

   c. Other uses and applications ____________________________________

      ____

      ____

3. Operating Characteristics

   a. Speed/Production

      1. Operating forward speed, mph: _____ average, _____ range

      2. Data Points per day: _____ average, _____ range

      3. Lane Miles of Pavement per day: _____ average, _____ range

      4. Data Points per lane mile: _____ average, _____ range

      5. Days per year equipment utilized: _____ average, _____ range

   b. Traffic control requirements on:

      1. High traffic volume facility:______________________________

      2. Low traffic volume facility: ______________________________

   c. Safety features: ____

      ____

      ____

   d. Data processing features: ____________________________________

      ____

   e. Calibration requirements: ____________________________________

      ____

4. Costs

   a. Purchase or first costs ______________________________

   b. Operating costs, including equipment, manpower and maintenance costs:

      1. Per data point: __________ average __________ range

      2. Per lane mile of pavement __________ average __________ range

   c. Maintenance requirements and costs

Problem Requiring Maintenance	Frequency of Repair	Approximate Costs

   d. Manpower

      1. Number of persons to operate ______________________________

      2. Qualifications of manpower for operation ______________________________

      ____

      ____

      3. Qualifications of manpower for repair and maintenance ______________

      ____

      ____

5. Photographs

   Please provide photographs of any of the equipment if conveniently available.

6. State Reports

   Please provide copies of state reports on this subject or give appropriate references.

NOTE: Please reproduce pages 3 and 4 of this questionnaire for each item of equipment utilized by the state for collecting pavement management information.

APPENDIX B

REFERENCES OBTAINED IN RESPONSE TO QUESTIONNAIRE

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APPENDIX C

RESULTS FROM QUESTIONNAIRE ON STRUCTURAL CAPACITY MEASURING EQUIPMENT (JUNE 1983)

TABLE C-1
GENERAL CHARACTERISTICS OF STRUCTURAL CAPACITY EQUIPMENT

Public Agency	Equipment Identification	Uses of Equipment: Input to Network Management	Input to Project Management	Other	Data Processing Feature	Calibration Requirements
Alabama	Benkelman Beam			•Overlay Design •Rehabilitation •PMS Underdevelopment	•Manual	•None
Alaska	FWD			•Maintenance Planning •PMS Underdevelopment	•HP 85 Computer	•Periodic Calibration of Sensors
Arizona	Dynaflect	No	Yes	•Joint Studies •PMS Developed	•None	•Daily Checks •Yearly Calibration
	FWD	No	Yes		Electronic Readout	•Daily Checks
Arkansas	Dynaflect	Yes	Yes	•Research Projects	None	•Provided by Manufacturer
California	Dynaflect	No	Yes	•Research	None	•Twice Daily
Florida	Dynaflect	No	Sometimes	•Research	•Handcoded for Computer	•Daily Frequency & Sensor Check
	FWD	No	No	•PVT Delfection	•HP 85	•Monthly
Idaho	Dynaflect	Yes			•HP 85 To IBM 4130 Mainframe	•Strobescope •Frequency Meter
	Benkelman Beam		No	•Overlay Design	None	•Dial Gauge
Illinois	Road Rater Benkelman Beam	No No	Sometimes Sometimes	•Research	Hand Calculator	•Daily •Dial
Indiana	Dynaflect	Sometimes	Sometimes	•Maintenance	•Printer & Mode Display	•Daily by Operator •Monthly by Electronic Tech
Iowa	Road Rater	Yes	Yes	•Research	•Coding Sheets	•Air Pressure
Kansas	Dynaflect	No	Yes		•Mag Tape to Plexus P40 Computer	•Monthly
Kentucky	Road Rater Benkelman Beam	Yes	Yes	•Overlay Design •Research Only		•Mass Movement
Louisiana	Dynaflect Benkelman Beam	Sometimes No	Sometimes No	•Voids Under PCC •Shoulders		•Geophones •Flywheels
Maryland	Road Rater	Sometimes	Yes	•Research	None	•Once Per Monthly in Field •2-3 Times Per Year Full System
Michigan	Road Rater FWD Benkelman Beam	No No	No No	•Overlay Design •Research	HP 85 HP 85	•Factory •Force Calibration •Factory
Missouri	Benkelman Beam		Sometimes	•Research		•Dial Gauges
Montana						
Nebraska	Dynaflects	Yes	Yes	•Overlay	Tape Storage of Data	•Twice Daily

TABLE C-1
GENERAL CHARACTERISTICS OF STRUCTURAL CAPACITY EQUIPMENT (Continued)

Public Agency	Equipment Identification	Uses of Equipment: Input to Network Management	Input to Project Management	Other	Data Processing Feature	Calibration Requirements
Nevada	Dynaflect		Yes	•Base Course Stability	•Manually	•Twice Daily
New Jersey	Benkelman Beam	No	No	•Research		•Deflection Plate
New York	Benkelman Beam		Sometimes		None	
Oklahoma	Benkelman Beam	No	Yes	•Research		
Oregon	Benkelman Beam Dynaflect	No Yes	Yes Sometimes	•Overlay	Manually TI-700 Plus Telephone	None Frequency Geophone
Pennsylvania	Road Rater	Sometimes	Yes	•Overlay Design •Load Restriction	•Digital Readout •Manual Recording	Static & Dynamic Load
S. Carolina	Benkelman Beam	No	No	•Research	None	None
S. Dakota	Dynaflect	Yes	Yes		•Digital Readout •Key Punch	•Geophones Daily
Tennessee	FWD	No	Yes		•Computerized	•Annually
Texas	Benkelman Beam Dynaflect	No Sometimes	No Yes	•Research Research	Cassette	Dial Gauge
Utah	Dynaflect	Yes	Yes			Geophones & Cyclic Loading device twice weekly
Virginia	Dynaflect	Sometimes	Yes	•Overlay Design		•Sensor Calibration
Washington	FWD	No	Yes		HP 85 & Stored on Tape	•Monthly
W. Virginia	Dynaflect			•Special Investigation	None	
Wisconsin	Benkelman Beam		Sometimes	•Spring Overloads	None	None
Wyoming	Dynaflect	Sometimes	Sometimes		None	None

TABLE C-2
OPERATING CHARACTERISTICS OF STRUCTURAL CAPACITY EQUIPMENT

Public Agency	Equipment Identification	Operating Forward Speed MPH		Data Points Per Day		Lane Miles of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Alabama	Benkelman Beam	Spot Operation only			20						
Alaska	FWD			150		30		5		150	
Arizona	Dynaflect	3	2-4	45	35-55	15	10-20	3		30	15-40
	FWD	2	1-3	35		11		3		20	
Arkansas	Dynaflect			175	150-250	48	35-60	3	2-5	100	60-140
California	Dynaflect	2	0-5	252	42-420	6	1-20	21	0-101	170	0-360
Florida	Dynaflect	2	1-4	200		15	10-40	14			
	FWD	0		480		0.75		260		100	
Idaho	Dynaflect	0		80	60-130	50	30-65	2	2-40	100	
	Benkelman Beam	0		40	20-60	40	20-60	1	1-20	5	1-20
Illinois	Road Rater			175	150-200	5	3-7	35	30-50	70	35-105
	Benkelman Beam			200	160-240	10	2-14	20	15-25	9	7-11
Indiana	Dynaflect	5		300	200-400	6	5-7	53	40-65	150	100-200
Iowa	Road Rater	5		210		70		3		45	
Kansas	Dynaflect	2		120	80-150	24	10-30	5		110	88-130
Kentucky	Road Rater Benkelman Beam	0		400		40		10		40	
Louisiana	Dynaflect	0		200		40		5		70	
	Benkelman Beam	0		30		6		5		10	
Maryland	Road Rater			200	150-300	10	5-15	13	5-53	160	90-200
Michigan	Road Rater			200		20		10			
	FWD										
	Benkelman Beam			50		5		10		40	
Missouri	Benkelman Beam	0-2		400		4		100		10	
Nebraska	Dynaflect	3		80	60-100	80	60-100	1	1-5	150	100-200

TABLE C-2
OPERATING CHARACTERISTICS OF STRUCTURAL CAPACITY EQUIPMENT (Continued)

Public Agency	Equipment Identification	Operating Forward Speed MPH		Data Points Per Day		Lane Miles of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Nevada	Dynaflects			450		15		30		120	
New Jersey	Benkelman Beam	0.25		30	20-50	1		30	20-50	10	5-15
New York	Benkelman Beam	1.5	1.5-2.5	160	130-285	1.0	0.75 1.75	158	53-185	30	20-50
Oklahoma	Benkelman Beam			150	125-175	30	20-40	5		120	80-150
Oregon	Benkelman Beam Dynaflect	3-4 0		200 5	150-300	5	2-10	23	21-16	150 180	125-175
Pennsylvania	Road Rater	0		110		10		11		75	
South Carolina	Benkelman Beam			60	40-100	6	2-10	10	5-30	15	10-20
South Dakota	Dynaflect	0		48	40-55	48	40-55	1		95	90-100
Tennessee	FWD	5		150		35	30-40	5		130	
Texas	Benkelman Beam Dynaflect	1 0		50 210	40-60 170-250	1 4	0.75-1.25 3-5	26 26		10 100	 90-110
Utah	Dynaflect	0		450	350-550	90	70-110	5		110	
Virginia	Dynaflect	3	3-5	276	52-322	15	5-20	18	10-52	83	45-84
Washington	FWD			150	100-250	15	10-20	10	5-20	100	
West Virginia	Dynaflect	0		50		5		5		30	
Wyoming	Dynaflect			100		200	0.5			60	

TABLE C-3
FIRST COSTS AND OPERATING COSTS OF STRUCTURAL CAPACITY EQUIPMENT

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile of Pavement				Repair & Maintenance Qualifications
Public Agency	Equipment Identification	Purchase Price	Average	Range	Average	Range	No.	Operational Qualifications	
Alabama	Benkelman Beam	$250 in 1950's					5	•Stamina •Read Dial Gauge •Note Keeping	•Minimal
Alaska	FWD	$95,000	$200		$7		2	•Minimal	•Electronics Technician
Arizona	Dynaflect	$25,000	$20		$60		3	•Mechanical and Electrical	•Mechanical & Electrical Training
	FWD	$30,000	$25		$75		3	•Machinery Hydraulic Equip.	
Arkansas	Dynaflect	$22,000	$1.84	$1.50-$2.50	$5.52	$3.68-$9.20	2	•Small Amount of Training	•Electronic Technician
California	Dynaflect	$18.000	$1.15	$0.85-$5.50	$24.15	$18.35-$367.00	1	•Technologist	•Electronics & Mechanical
Florida	Dynaflect	$30,000 Trailer					2	•Electronic & Mechanical	•Electronic & Mechanical
	FWD	$80,000					2	•Electronic & Mechanical	•Electronic & Mechanical
Idaho	Dynaflect	$100,000	$13.00	$10.00-$20.00	$130	$90-$150	5	•Technician & 3 Traffic Control	•Electronic
	Benkelman Beam	$1,300	$10.00		$10.00	5-15	6	•8 Traffic Control	•Technician
Illinois	Road Rater	$24,500 + Two Vehicle	$ 2.20				4	•2 Technicians •2 Maintenance	•Technician
	Benkelman Beam	$200	$ 1.55		$31.00		3	•Technician •Truck Driver	•Minimal
Indiana	Dynaflect	$30,000	$81.24 Per Hour					•Technician	•Electrical •Mechanical
Iowa	Road Rater	$25,000 in 1976	$ 6.31		$18.92		4	•2 People for Safety	•Technician
Kansas	Dynaflect	$33,551	$15.00	$10-$18	$75		1	•Technician	•Mechanical •Electrical
Kentucky	Road Rater	$35,000 in 1971					2	•Technicians	•Mechanical •Electrical
	Benkelman Beam						4	•Technician	
Louisiana	Dynaflect	$25,000	$ 8.80	$44			2	•Technician	•Mechanical
	Benkelman Beam	$200	$ 4.27	$21.33			2	•Technician	•Technician
Maryland	Road Rater	$50,000 Trailer & Two Vehicle	$ 2.76	$1.80-$3.00	$55.29	$45-$65	2	•Mechanics •Electronics	•Mechanics •Electronics

TABLE C-3
FIRST COSTS AND OPERATING COSTS OF STRUCTURAL CAPACITY EQUIPMENT (Continued)

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile of Pavement			Operational	Repair & Maintenance
Public Agency	Equipment Identification	Purchase Price	Average	Range	Average	Range	No.	Qualifications	Qualifications
Minnesota	Road Rater	$30,000					2	•Electrical	•Electrical
	FWD	$95,000					2	•Electrical	•Electrical & Mechanical
	Benkelman Beam						3		
Missouri	Benkelman Beam	$300 in 1972	$1.50		$150		7		
Nebraska	Dynaflect						2	•Technician	•Technician
Nevada	Dynaflect	$18,900 + Towing Vehicle	$0.78	$0.58-$1.17	$23.31	$17.48-$34.96	2	•Technician	•Technician
New Jersey	Benkelman Beam	$1,000					3	•Technician •Driver	
New York	Benkelman Beam	$150 in 1964	$2.00	$1.00-$5.00	$ 6.00	$300-$800	3		
Oklahoma	Benkelman Beam	$800	$2.36	$2.25-$2.50	$11.80	$11.25-$12.50	6	•Technician	•Technician
Oregon	Benkelman Beam	$800 in 1977	$3.20	$2.10-$4.30	$80.00	$64-$320	5	•Technician	
	Dynaflect	$50,000 in 1979	$120				3	•Electronics	•Electronics
Pennsylvania	Road Rater	$32,000	$8.00		$88.00		3	•Technician •Flag Men	•Mechanical Electrical
South Carolina	Benkelman Beam	$ 700	$4.00	$3.00-$5.00			3 or 4	•Technician	
South Dakota	Dynaflect	$22,185 in 1981	$6.25	$6.00-$6.50	$ 6.25	$ 6.00-$6.50	2	•Technician	•Mechanical •Electrician
Tennessee	FWD	$110,000	$3.00	$2.50-$3.50	$12.00	$10.00-$14.00	2	•Technicians	
Texas	Benkelman Beam	$ 800	$2.00	$1.00-$3.00	$100	$75-$125	1	•Technician	
	Dynaflect	$ 10,000-$20,000	$1.00	$0.60-$1.40	$ 50	$38.00-$62.00	2	•Technician	•Electronics
Utah	Dynaflect	$ 17,000	$1.25	$1.15-$1.35	$1.25	$ 1.15-$1.35	2	•Technician	•Electrical •Mechanical
Virginia	Dynaflect	$ 20,000	$1.00	$0.80-$8.00	$17.50	$10.00-$50.00	1	•Technician + Traffic Control	•Electronics
Washington	FWD	$ 86,500	$3.75	$2.24-$5.60	$56.00	$23.00-$112.00	2	•Technician	•Technical
West Virginia	Dynaflect	$ 13,520					2		
Wisconsin	Benkelman Beam						3	•Technician	
Wyoming	Dynaflect	$ 15,000	$12.00		$ 6.00		3	•Technician	

TABLE C-4
SAFETY FEATURES OF STRUCTURAL CAPACITY EQUIPMENT

Public Agency	Equipment Identification	Traffic Control Requirements: High Traffic Facilities	Traffic Control Requirements: Low Traffic Facilities	Other Safety Features
Alabama	Benkelman Beam	Close Work Lane, Cones, Early Warning Sign, Flagmen	Early Warning Sign Flagmen	None on Equipment
Alaska	FWD	Pilot Vehicle to Warn Traffic	Arrow Board	
Arizona	Dynaflect	Warning Lights, Arrow Board Flagmen, Signs.		
Arkansas	Dynaflect	Stop Traffic in One Lane	Stop Traffic in One Lane	
California	Dynaflect	Pilot Car or Lane Closure	Flagmen	Breakaway Brakes, Enclosed Flywheels & Drive Motor
Florida	Dynaflect	Flashing Arrow if Multi-lane	Arrow & Flagging Crew Strobe Lights	
	FWD	Flashing Arrow, Cones, Flagmen	Flashing Arrow	Strobe Lights, Vehicle Alarm System
Idaho	Dynaflect	Sign Trucks Lead, Trail & Crash Attennator	Attennator Truck Radio Communications Lead, Trail & Crash Attennator	Arrow Board, Strobe Lights Flagman, Sign
Illinois	Road Rater	Close Lane	Sign, Flagman	Flashing Lights
	Benkelman Beam	Close Lane	Flagman	Flashing Lights
Indiana	Dynaflect	Arrow Boards, Signs, Flagman		
Iowa	Road Rater	Safety Vehicle	Safety Vehicle	Lights, Signs
Kansas	Dynaflect	Sign Truck	Sign Truck	
Kentucky	Road Rater Benkelman Beam			Signs, Cones, Arrow Boards
Louisiana	Dynaflect			Flagmen, Arrows, Lights
	Benkelman Beam			Flagmen, Arrow, Lights
Maryland	Road Rater			Dump Trucks with Arrow Boards
Minnesota	Road Rater FWD Benkelman Beam	Signs Close Lane	Sign Flagman	Arrow Board
Missouri	Benkelman Beam			Signs, Flagmen, Arrow Board
Nebraska	Dynaflect	Arrow Board Flagman	Follow Vehicle	
Nevada	Dynaflect			Signs, Cones, Flagmen
New Jersey	Benkelman Beam			Cones, Signs
New York	Benkelman Beam			Signs, Arrow Boards, Flagmen
Oklahoma	Benkelman Beam	Following Truck	Following Truck	Flagman
Oregon	Benkelman Beam			Numerous
	Dynaflect			Numerous
South Carolina	Benkelman Beam	Block Lane	Block Lane	
South Dakota	Dynaflect			Light, Signs
Tennessee	FWD	Testing of Peak Hours		Signs, Flagmen

TABLE C-4
SAFETY FEATURES OF STRUCTURAL CAPACITY EQUIPMENT (Continued)

Public Agency	Equipment Identification	Traffic Control Requirements High Traffic Facilities	Traffic Control Requirements Low Traffic Facilities	Other Safety Features
Texas	Benkelman Beam			Cones, Signs, Flagmen
	Dynaflect			Cones, Signs, Flagmen
Vermont	Dynaflect	Follow Vehicles	Follow Vehicles	Extensive
Washington	FWD	Lane Closure	Lane Closure	
West Virginia	Dynaflect			Sign & Flagmen
Wisconsin	Dynaflect	Follow Vehicle		Arrow, Flagmen

TABLE C-5
MAINTENANCE REQUIREMENTS AND COSTS OF STRUCTURAL CAPACITY EQUIPMENT

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency of Repair	Approximate Costs
Alabama	Benkelman Beam	Wear Batteries	Seldom Each Use Period	Unknown $5.00
Alaska	FWD	Pressure Seitch	Annually	$1.00
Arizona	Dynaflect FWD	Electrical Hydraulic Seals	Annually Annually	
Arkansas	Dynaflect	Minor, Large Amount of Preventive Maintenance	Relatively Inexpensive, Replacement Parts are High	
California	Dynaflect	Flywheel Out of Adjustment	3 Times Per Year	
Florida	Dynaflect FWD	Loose Parts Bearings Routine Cleaning, Grease, Oil etc.	Every Road Trip 3 Times Per Year	
Idaho	Dynaflect	Lift System for Geophones Geophones Replacement	Monthly Monthly	$ 50.00 $ 200.00
Illinois	Road Rater Benkelman Beam	Hydraulic Leaks, Trailer, Electronic None	0-3 Days Per Month	$1,000/Yr. $1,600/Yr.
Indiana	Dynaflect	Pillow Blocks Luble Force Wheels Sensor Carriage	6 months Biweekly Annually	$ 50.00 $ 10.00 $ 200.00
Iowa	Road Rater	Sensor Wires Hydraulic Fluids General	Annually Annually Annually	$ 50.00 $ 50.00 $ 400.00
Kansas	Dynaflect	Tow Vehicle Power System Mechanical-Wear Alignment Electrical Replace Mechanical Parts	Annually Annually Annually Biannually	$ 300.00 $ 100.00 $ 100.00
Kentucky	Road Rater Benkelman Beam	Wires, Circuit Board, Meter Hydraulic Seals		
Louisiana	Dynaflect Benkelman Beam	Sensor Rack, Force Motor Dial Gauge	2-3 yrs. 3-5 yrs.	$ 450.00 $ 40.00
Maryland	Road Rater	Engine Maintenance Electrical		$ 60.00 $ 30.00
Minnesota	Road Rater FWD Benkelman Beam	Electrical	Often	
Missouri	Benkelman Beam	Bearings, Dial Stem Cleaning Calibration	Semiannually	$ 100.00
Nebraska	Dynaflect			
Nevada	Dynaflect	Sensor Bar	Annually	
New Jersey	Benkelman Beam			$20.00-$50.00
New York	Benkelman Beam	Oil Hinge Points Annually		
Oklahoma	Benkelman Beam	Buzzer	Weekly	$ 1.50
Oregon	Benkelman Beam Dynaflect	Bolts, Fullrum, Buzzer, Batteries Geophones, Computer Terminal	Annually Annually	$ 50.00 $6,800.00
Pennsylvania	Road Rater	Sensors Hydraulic Cylinder	Annually Annually	$ 140.00 $ 380.00

TABLE C-5
MAINTENANCE REQUIREMENTS AND COSTS OF STRUCTURAL CAPACITY EQUIPMENT (Continued)

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency of Repair	Approximate Costs
South Carolina	Benkelman Beam	Repairs & Vehicle		
South Dakota	Dynaflect	Force Motor	3 Years	$ 100.00
		Hydro Lift Motor	2 Years	$ 150.00
		Alternator	2 Years	$ 100.00
		Geophones, Other Parts	Annually	$ 550.00
Tennessee	FWD			
Texas	Benkelman Beam	Batteries	2 Months	$ 5.00
	Dynaflect	Lift Assembly	6 Months	$ 50.00
		Electronics	2 Months	$ 50.00
		Geophones	18 Months	$ 100.00
Utah	Dynaflect	Electrical	4 Months	$225.00
		Retread Force Wheels	Annually	$150.00
		Mechanical	Annually	$600.00
Virginia	Dynaflect	Pillow Blocks		$34.00-$64.00
		Noise in Control Unit		$115.00
		Regular Maintenance	Monthly	$ 33.44

APPENDIX D

RESULTS FROM QUESTIONNAIRE ON SURFACE DISTRESS MEASURING EQUIPMENT (JUNE 1983)

TABLE D-1
GENERAL CHARACTERISTICS OF SURFACE DISTRESS MEASURING TECHNIQUES

		Uses of Equipment				
Public Agency	Equipment Identification	Input To Network Management	Input To Project Management	Other	Data Processing Feature	Calibration Requirements
Connecticut	Photologger	Sometimes	Yes	Court Testimony Maintenance Traffic, Signal Studies Road Design		
Illinois	Dalamtect	No	Yes	Research	Available	Daily
Kansas	Photolog	Yes	Yes	Safety	Mag Tape	Weekly
	Per 2000	Yes	Sometimes		Mag Tape	Distance
Louisiana	Photologger			Accident Investigation	None	None
Missouri	Pavement Edge Strain Gauge	Sometimes	Sometimes		Manual	Strain Gauge
New York	Visual Condition Survey	Yes	Yes			Field Training
	Photolog	Yes	Yes			
Ohio	Photolog Tech West	No	Sometimes		Digital Cartridges	Two Times Daily
	Photolog IMC	No	Sometimes		None	None
South Dakota	Photolog	Yes	Yes		No	Distance
Texas	Vertical Photolog	No	No	Local	Manual	None
Wisconsin	Photolog	Yes		Accident Investigation	Digital Recorder	None

TABLE D-2
OPERATING CHARACTERISTICS OF SURFACE DISTRESS MEASURING TECHNIQUES

Public Agency	Equipment Identification	Operating Foreward Speed MPH		Data Points Per Day		Lane Miles Of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Delaware	Photologger										
Illinois	Dezamtech	3	1-5								
Kansas	Photolog	40	1-55	30,000		300		100		50	
Kentucky	Photologger	40								85	
Missouri	Pavement Edge Strain Gauge	0		30						10	
New York	Visual Condition Survey	35	30-45			450				50	
	Photolog	45	0-85	15,000	5,000-25,000	150	50-250	100		125	75-125
Ohio	Photolog Tech West	40	20-55	10,000	3,000-15,000	100	30-150	100		120	60-185
	Photolog IMC	40	20-55	10,000	3,000-15,000	100	65-185	100		120	65-185
South Dakota	Photolog	45			15,000-22,500		180-225	100			
Texas	Vertical Photologger	10				3	1-5			10	
Wisconsin	Photolog					150		100		185	

TABLE D-3
FIRST COSTS AND OPERATING COSTS OF SURFACE DISTRESS MEASURING TECHNIQUES

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile of Pavement		Operational		
Public Agency	Equipment Identification	Purchase Price	Average	Range	Average	Range	No.	Qualifications	Repair & Maintenance Qualifications
Delaware	Photologger	41,000			8.56 in 1975		2	Photography Mechanical	Special Equipment Prepared At Factory
Illinois	Delament	100,000-15,000					1		Electrical
Kansas	Photolog Per 2,000	84,000 6,895	 1.55		8.00 4.65		2 2	Technical Technical	Technical BSEE
Kentucky	Photologger	Camera 8,331 Analyzer 4,530			 2.41		 2	Technical	Electronics
Missouri	Pavement Edge	2,000	100				5	Electronics	Electronics
New York	Visual Condition Photolog	1,000 20,000 in 1979	 0.18		2.50 18	 10-25	2 2	Technician Photographic	
Ohio	Photolog Tech West Photolog IMC	90,000 12,000	.114 .114	.08 to 0.16 .10 to 14	11.40 11.40	8-16 10-14	2 2		Electronics Electronics
South Dakota	Photolog	23,000 includes VAL	13.22		13.22		2		
Texas	Vertical Photologger	5,000	0.15		45		2	Technical	Photography
Wisconsin	Photolog	100,000					3	Photography	Electronics

TABLE D-4
SAFETY FEATURES OF SURFACE DISTRESS MEASURING TECHNIQUES

Public Agency	Equipment Identification	Traffic Control Requirements High Traffic Facilities	Low Traffic Facilities	Other Safety Features
Delaware	Photologger			
Illinois	Delamtect	Lane Closure		Arrow Board, Signs, Flagman
Kansas	Photolog Per 2,000	None None	None None	Vehicle Lights
Kentucky	Photologger	None	None	
Missouri	Pavement Edge Strain Gauge			Signs, Cones, Flagmen, Arrow Board
New York	Visual Condition Survey Photolog			Flashers Maintain Open Highway
Ohio	Photolog Tech West Photolog IMC	None None	None None	
South Dakota	Photolog			Lights C-B Radio
Wisconsin	Photolog	None	None	

TABLE D-5
MAINTENANCE REQUIREMENTS AND COSTS OF SURFACE DISTRESS MEASURING TECHNIQUES

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency of Repair	Approximate Costs
Connecticut	Photologger			
Illinois	Delamtect	No Two System Have Failures Have Been the Same		
Kansas	Photolog	Camera System	2 Years	$3,500.00
		Recorder	4 Months	$1,000.00
	Per 2,000	Resistors		$ 1.25
Kentucky	Photologger	Autex Opometer		$ 5.00
Missouri	Pavement Edge Strain Gauge	Calibration	Semiannually	$500.00
		Circuit Connections	Annually	$100.00
		Mount Strain Gauge	5 Years	$200.00
New York	Visual Condition Survey Photolog		Annually	$500.00
Ohio	Photolog Tech West	Vertical Gyro, Camera	Annually	$1,600
		Pendulum	4 Years	
	Photolog IMC	Camera	Annually	$ 600.00
South Dakota	Photolog	Camera Motor		$ 500.00
		Check Camera		$ 975.00
		L.E.D. In Control Panel	2 Years	
Texas	Vertical Photologger	Shutter	6 Months	$ 200.00

APPENDIX E

RESULTS FROM QUESTIONNAIRE ON FRICTION MEASURING EQUIPMENT (JUNE 1983)

TABLE E-1
GENERAL CHARACTERISTICS OF FRICTION MEASURING EQUIPMENT

		Uses of Equipment				
Public Agency	Equipment Identification	Input to Network Management	Input to Project Management	Other	Data Processing Feature	Calibration Requirements
Alabama	Locked Wheel Skid Trailer			Statewide Survey Every Two Years	Manual From Digital Display	PVT Test Section Force Plate At Texas A&M every 2-3 Yrs.
Arizona	Mu-Meter	Yes	Yes		Paper Tape Printed Results	Weekly Checks on Calibration Board
Arkansas	Locked Wheel Skid Trailer	Sometimes	Sometimes	Research	Tape Printout	Annually Frequently on Dept. Owned Pad
California	Locked Wheel Skid Trailer	Yes	Sometimes	Research Legal & Claims Requests		Force & Water Every 4 to 6 Months Distance Every 1 to 2 Months
Connecticut	Locked Wheel Skid Trailer	Yes	Yes	High Accident Area Experimental Paving Materials	4 Channel Strip Chart 8 Level Tape for Computer Input	Force Plate Annually Skid Center Every 2 Years Internal 2 Times Per Day
Delaware	Locked Wheel Skid Trailer	Yes	Sometimes	Safety Planning Accident Location	DVM Printer	1 Day Per Month Skid Center Every 2 Years
Florida	Locked Wheel Skid Trailer			Research Inventory	Hand Coded for Computer	30-45 Day Interval on Bearing Plate Skid Center Every 2 Years
Georgia	Locked Wheel Skid Trailer	No	Sometimes	Accident Sites Test Sections Inventory		Yearly Air Bearing Calibration Monthly correlation between Trailers
Hawaii	Locked Wheel Skid Trailer	Yes	Yes	Research		Skid Center Every 3 Years Daily Sikd Pad Force Plate
Idaho	Locked Wheel Skid Trailer	Yes		Maintenance & Seal Coat Scheduling	HP85 to IBM 4130 Main Frame	Skid Center Tire Pressure Speed Water Calibration
Illinois	Locked Wheel Skid Trailer	Yes	Yes	Research	CPU in One Tester	For One Arm or Force Plate Monthly or After Repair of Brakes

TABLE E-1
GENERAL CHARACTERISTICS OF FRICTION MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Uses of Equipment: Input to Network Management	Uses of Equipment: Input to Project Management	Uses of Equipment: Other	Data Processing Feature	Calibration Requirements
Indiana	Locked Wheel Skid Trailer	Sometimes	Sometimes	Accident Prevention	On Board Computation of SN Keyboard	Once Per Month on Force Plate Once Per Year At Skid Center Once Per Day on Standard Surface
Iowa	Locked Wheel Skid Trailer	Yes	Research		Tape Printout Manual Coded for Key-punch	Biweekly Platform Water Calibration Speed Pavement Sections
Kansas	Locked Wheel Skid Trailer	Yes	Yes		Tape Printer	Daily Electronics Monthly Load & Traction
Kentucky	Locked Wheel	Yes	Yes	Accident Investigation		
Louisiana	Locked Wheel Skid Trailer	Yes	No			
	British	Sometimes	Sometimes	Where Trailer Cannot be Used	None	
Maryland	Locked Wheel Skid Trailer	No	No	Accident Investigation		Monthly In-Houses Biannually Nationally
Massachusetts	Locked Wheel Skid Trailer	Yes	Yes	Accident Areas	Data Logger	Skid Center Every 2 Years
Michigan	Locked Wheel Skid Trailer	Sometimes	Sometimes	Research	Analog-Digital	Force Plate
Minnesota	Locked Wheel Skid Trailer	Sometimes	Sometimes	Accident Investigation Mixture Evaluation	Cassette Tape	Skid Center Every 2 Years
Missouri	Locked Wheel Skid Trailer	Yes	Yes	Research	Printer Keypunch By Hand	Force Speed Distance
Nebraska	Locked Wheel Skid Trailer	Yes	Yes	Research Accident Investigation		Once or Twice Per Year
Nevada	Locked Wheel Skid Trailer Cox	Yes			Cassette Recorder	Annual Force Plate Skid Center Every 2 Years
	Law	Yes			Manual	Annual Force Plate Skid Center Every 2 Years
New Hampshire	Locked Wheel Skid Trailer		Sometimes	Safety	Manual	Skid Center Annually
New Jersey	Locked Wheel Skid Trailer	Yes		Research	Cassette	Skid Center Annually Force Plate Monthly

TABLE E-1
GENERAL CHARACTERISTICS OF FRICTION MEASURING EQUIPMENT (Continued)

		Uses of Equipment				
Public Agency	Equipment Identification	Input to Network Management	Input to Project Management	Other	Data Processing Feature	Calibration Requirements
New York	Locked Wheel Skid Trailer	No	Sometimes	Research		Skid Center Force Plate
North Carolina	Locked Wheel Skid Trailer	Yes	Sometimes	Accident Investigation Research	Strip Chart Computer Data Bank Printer	Torque Bar
Ohio	Locked Wheel Skid Trailer	Sometimes	Sometimes		Digital Data Logger Cassette	Skid Center Annually Local Test PVTS Force Plate
Oklahoma	Locked Wheel Skid Trailer		Sometimes			Strain Gauge Calibrated 4 Months Control Section Monthly
Oregon	Locked Wheel Skid Trailer	Yes	Sometimes	Accident Investigation	Digital Display Printed Tape	Air Platform
Pennsylvania	Locked Wheel	Sometimes	Yes	Accident Investigation	Mag & Paper Tape	Load Speed Distance Water
South Carolina	Locked Wheel Skid Trailer	Yes	No	Accident Investigation	Paper Tape Cassette	Skid Center Every 2 Years
South Dakota	Locked Wheel Skid Trailer	Yes	Yes		Paper Tape Printer	Skid Center Every 2 Years Water 2-3 Per Year
Tennessee	Locked Wheel	No		Accident Study	On Board Computer	Yearly
Texas	Locked Wheel Skid Trailer	No	Yes	Research Accident Investigation	Cassette	Skid Center Annually
Utah	Mu-Meter	Yes	Yes	Accident Investigation	Coding Sheets	Reference Surface
Virginia	Locked Wheel Skid Trailer	Yes	Yes	Accident Reduction	Printer, Logger Encoder	Skid Center Every 2 Years
Washington	Locked Wheel Skid Trailer	Yes	Yes	Problem Areas on Call	None	Daily Skid Center Every 2 Years
West Virginia	Locked Wheel Skid Trailer	Sometimes	Sometimes	None		Skid Center Yearly
Wisconsin	Locked Wheel Skid Trailer		Sometimes		Auto Recorded	Skid Center Every 2 Years Water Flow
Wyoming	Locked Wheel Skid Trailer	Sometimes	Sometimes	Isolate Problem Areas	None	Skid Center Every 2 Years

TABLE E-2
OPERATING CHARACTERISTICS OF FRICTION MEASURING EQUIPMENT

Public Agency	Equipment Identification	Operating Foreward Speed, MPH		Data Points Per Day		Lane Miles of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Alabama	Locked Wheel Skid Trailer	40		200		200		5 Skids Per Data Point 1 Data Point Per Mile		120	
Arizona	Mu-Meter	40		200		250		1		150	
Arkansas	Locked Wheel Skid Trailer	40		520		260		2		160	
California	Locked Wheel Skid Trailer		20-55	300	200-300	200	150-300	2	0.5-6	200	
Connecticut	Locked Wheel Skid Trailer	40	35-45	60	5-125			3	Up to 40	25	Up to 100
Florida	Locked Wheel Skid Trailer	40	20-80					3	3-5		
Georgia	Locked Wheel Skid Trailer	40		200		100		2		200	
Hawaii	Locked Wheel Skid Trailer	40		960		240	220-260	4	2-6	120	
Idaho	Locked Wheel Skid Trailer	40		150	100-300	120	30-200	1	1-10	105	75-150
	Mu-Meter	40	20-60	100	50-150	160		1	1-5	30	
Illinois	Locked Wheel Skid Trailer	40	30-50							120	80-150
Indiana	Locked Wheel Skid Trailer	30	20-50	200	140-250	120	100-175	1.67	1-3	110	90-130
Iowa	Locked Wheel Skid Trailer	40	38-42	200		100		2		65	
Kansas	Locked Wheel Skid Wheel	40-55	30-55	200	20-300	70	10-100	5	2-10	150	100-200
Kentucky	Locked Wheel Skid Trailer	40									
Louisiana	Locked Wheel Skid Trailer British	40	20-60	50	0-100	100	0-200	2		140	0-250

TABLE E-2
OPERATING CHARACTERISTICS OF FRICTION MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Operating Forward Speed, MPH		Data Points Per Day		Lane Miles of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Maryland	Locked Wheel Skid Trailer	40	20-55	250	28-300	120	30-200	3	2-10	100	80-130
Massachusetts	Locked Wheel Skid Trailer	40	20-50	100	50-200	50	20-100	2	2-5	100	70-200
Michigan	Locked Wheel Skid Trailer	40	1-80	150	0-800	60	0-240	3	3-22	120	
Minnesota	Locked Wheel Skid Trailer	40	25-55	90		30		3	2-5	100	
Missouri	Locked Wheel Skid Trailer	40		400		80		5	3-8	140	
Nebraska	Locked Wheel Skid Trailer	40	30-50			100	75-150	2		200	150-250
Nevada	Locked Wheel Skid Trailer — Cox Law	40 40		150 150		150 150		1 1		90 35	
New Hampshire	Locked Wheel Skid Trailer	40								10	8-12
New Jersey	Locked Wheel Skid Trailer	40	20-60	400		80	60-100	1		120	
New York	Locked Wheel Skid Trailer	40	20-60	400	200-600					100	70-135
North Carolina	Locked Wheel Skid Trailer	40	30-50		60-90		100-150	2			200-220
Ohio	Locked Wheel Skid Trailer	40	35-45	236	51-499	123	27-266	1.9		53	23-94
Oklahoma	Locked Wheel Skid Trailer	40						4		100	
Oregon	Locked Wheel Skid Trailer	40	20-55	100	10-150	50	25-75	2		100	50-150
Pennsylvania	Locked Wheel Skid Trailer	40	25-45	160		16		10		150	
South Carolina	Locked Wheel Skid Trailer	40	38-42	600	300-900	200	100-300	3	2-10	200	150-250

TABLE E-2
OPERATING CHARACTERISTICS OF FRICTION MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Operating Foreward Speed, MPH		Data Points Per Day		Lane Miles of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
South Dakota	Locked Wheel Skid Trailer	40		175	150-200	175	150-200	1		95	80-105
Tennessee	Locked Wheel Skid Trailer	40		80		40		2		90	
Texas	Locked Wheel Skid Trailer	40	38-42	1200		240	200-280	1	1-5	60	40-80
Utah	Mu-Meter	40	39-41	80	60-100	130	100-160	1		100	80-120
Virginia	Locked Wheel Skid Trailer	40	39-41	100		33		3	3-5	220	195-245
Washington	Locked Wheel Skid Trailer	40	20-40	200	100-300	200	100-300	1		120	60-180
West Virginia	Locked Wheel Skid Trailer	55								180	
Wisconsin	Locked Wheel Skid Trailer	40		91		45		2		61	
Wyoming	Locked Wheel Skid Trailer	40		300		150		2		80	

TABLE E-3
FIRST COSTS AND OPERATING COSTS OF FRICTION MEASURING EQUIPMENT

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile of Pavement		Operational		Repair & Maintenance Qualifications
Public Agency	Equipment Identification	Purchase Price	Average	Range	Average	Range	No.	Qualifications	
Alabama	Locked Wheel Skid Trailer	33,880 in 1969 Vehicle & Skid Trailer					2	Knowledge of Skid Testing System & State Network of Highways	Calibration Procedures
Arizona	Mu-Meter	25,000	7.00		7.00		1	Mechanical & Electrical Equipment	Mechanical & Electrical Equipment
Arkansas	Locked Wheel Skid Trailer	35,000	0.89		1.78		2	Vehicle & Computer	Mechanical & Electrical
California	Locked Wheel Skid Trailer	140,000	3.00	2.60 to 4.55	4.55	3.00 to 6.10	2	Technician	Technician
Connecticut	Locked Wheel Skid Trailer	82,000	250 Per Day				2	Driver Electronics	Vehicle Repair & Electronics
Delaware	Locked Wheel Skid Trailer	27,000 in 1971	1.25		2.50		2	Driver Electronics	Electronics Mechanical
Florida	Locked Wheel Skid Trailer	65,000 in 1970					1	Engineer Technician	Electronic & Mechanical
Georgia	Locked Wheel Skid Trailer	25,000 in 1969					1	Electronics & Mechanical	Electronic & Mechanical
Hawaii	Locked Wheel Skid Trailer	65,000					2		Mechanics Technicians
Idaho	Locked Wheel Skid Trailer	50,000 in 1975	4.00		4.00		2	Technician	Electronics
	Mu-Meter	60,000					2	Technician	Electronics
Illinois	Locked Wheel Skid Trailer	67,500	175 Per Test Site	150-260			2		Electronic Programming Mechanical
Indiana	Locked Wheel Skid Trailer	60,000	1.10	0.87 to 1.55	1.80	1.25 to 2.16	2	Electronic Mechanical	Electronic Mechanical
Iowa	Locked Wheel Skid Trailer	75,000 in 1975	3.13		6.27		2	Technicians	Electronics
Kansas	Locked Wheel Skid Trailer	100,000	0.20	0.10 to 0.50	1.00	0.50 to 2.00	1 or 2		Mechanical Electrical
Kentucky	Locked Wheel Skid Trailer						1		Technical

TABLE E-3
FIRST COSTS AND OPERATING COSTS OF FRICTION MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Purchase Price	Operating Costs: Per Data Point Average	Operating Costs: Per Data Point Range	Operating Costs: Per Lane Mile of Pavement Average	Operating Costs: Per Lane Mile of Pavement Range	Manpower: Operational No.	Manpower: Operational Qualifications	Manpower: Repair & Maintenance Qualifications
Louisiana	Locked Wheel Skid Trailer British	99,960 Plus Truck 1800 in 1979	22.36 Per Hour				1		BSEE
Maryland	Locked Wheel Skid Trailer	91,000 to 114,000	0.53		1.06		2	Technical	Electronic Mechanical
Massachusetts	Locked Wheel Skid Trailer	75,000			50.00		2	Mechanical Electronic	Mechanical Electronics
Michigan	Locked Wheel Skid Trailer	88,000 Plus Vehicle (K.J. Law)					2	Technicians	Mechanical Electrical
Minnesota	Locked Wheel Skid Trailer	70,000	6.27		20		2	Technical	
Missouri	Locked Wheel Skid Trailer	85,000 in 1980	5	4-10	25		2	Electronics	Electrical Mechanical
Nebraska	Locked Wheel Skid Trailer	78,000					1 or 2	Technician	Technician
Nevada	Locked Wheel Cox	142,900	2.33	1.55 to 4.66	2.33	1.55 to 4.66	2	Technician	Technician
	Skid Trailer Law	57,910	2.33	1.55 to 4.66	2.33	1.55 to 4.66	2	Technician	Technician
New Hampshire	Locked Wheel Skid Trailer				3.75	3-4	2		
New Jersey	Locked Wheel Skid Trailer	100,000	2.00		10.00		2	Electrical	Electronics Mechanical
New York	Locked Wheel Skid Trailer		6.00				2	Technician	Electronics Mechanical
North Carolina	Locked Wheel Skid Trailer	49,687 Includes Towing Unit				3-4	1	Technician	
Ohio	Locked Wheel Skid Trailer	60,000	5.76		10.95		2	Technician	Electrical Mechanical
Oklahoma	Locked Wheel Skid Trailer						2	Technical	
Oregon	Locked Wheel Skid Trailer	52,000 in 1973	4.95		9.80		2	Technician	Electrical Mechanical

TABLE E-3
FIRST COSTS AND OPERATING COSTS OF FRICTION MEASURING EQUIPMENT (Continued)

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile of Pavement		Operational		Repair & Maintenance
Public Agency	Equipment Identification	Purchase Price	Average	Range	Average	Range	No.	Qualifications	Qualifications
Pennsylvania	Locked Wheel Skid Trailer	96,000 - 100,000	5.00		50.00		2	Technician	Electrical Mechanical
South Carolina	Locked Wheel Skid Trailer	90,000	0.50	0.25 to 1.50	1.50	0.75 4.50	1	Technician	Electronics Mechanics
South Dakota	Locked Wheel Skid Trailer	57,000 in 1975	3.90	3.75 to 4.10	3.90	3.75 to 4.10	2	Technician	Mechanical Electrical
Tennessee	Locked Wheel Skid Trailer	58,000	3.38	-4.00	6.75	-8.00	2	Technician	Electronics
Texas	Locked Wheel Skid Trailer	50,000	0.58	0.35 to 1.75	1.75	1.50 to 2.00	2	Technician	Electronics
Utah	Mu-Meter	10,000 Plus Two Vehicle	0.90	0.80 to 1.00	0.90	0.80 to 1.00	1	Technician	Electrical Mechanical
Virginia	Locked Wheel Skid Trailer	98,500	5.25	5-6	15.00	15.20	2	Electronics Mechanics	Electronics
Washington	Locked Wheel Skid Trailer	60,585	1.45	1.25 to 2.50	1.45	1.25 to 2.50	2	Technician	Technician
West Virginia	Locked Wheel Skid Trailer	125,000					2		
Wisconsin	Locked Wheel Skid Trailer		3.40		6.96		2	Technician	Electronics Mechanics
Wyoming	Locked Wheel Skid Trailer	90,000	5		10		2	Technician	

TABLE E-4
SAFETY FEATURES OF FRICTION MEASURING EQUIPMENT

Public Agency	Equipment Identification	Traffic Control Requirements		Other Safety Features
		High Traffic Facilities	Low Traffic Facilities	
Alabama	Locked Wheel Skid Trailer	None	None	Rotary Light, Flashing Sign on Vehicle
Arizona	Mu-Meter	None	None	Warning Sign on Back
Arkansas	Locked Wheel Skid Trailer	None in Rural Area Police Escort Van In Urban Area	None	Caution Sign on Rear of Van Amber Strobe Bar on Cab
California	Locked Wheel Skid Trailer	None	None	
Connecticut	Locked Wheel Skid Trailer	None	Police Protection at Intersection	Flashing Lights
Delaware	Locked Wheel Skid Trailer	None	None	Strobe Light on Vehicle Flashing Yellow Lights on Vehicle
Florida	Locked Wheel Skid Trailer			Strobe Lights on Tow Truck Flashing Red Lights on Trailer
Georgia	Locked Wheel Skid Trailer	None	None	
Hawaii	Locked Wheel Skid Trailer	None	None	Warning Lights Lights on Test Vehicle
Idaho	Locked Wheel Skid Trailer	Lights	4 Way Flashers	
Illinois	Locked Wheel Skid Trailer	Follow Vehicle Police at Cross Street	None	
Indiana	Locked Wheel Skid Trailer	Police Escort	None	
Iowa	Locked Wheel Skid Trailer	None	None	
Kansas	Locked Wheel Skid Trailer	None	None	
Kentucky	Locked Wheel Skid Trailer	None	None	
Louisiana	Locked Wheel British	None	None	Police, Cones, Flagmen
Maryland	Locked Wheel Skid Trailer	Following Vehicle	None	Intersection Control
Massachusetts	Locked Wheel Skid Trailer	None	None	Strobe Lights
Michigan	Locked Wheel Skid Trailer	Occasional	Occasional	
Minnesota	Locked Wheel Skid Trailer	None	None	
Missouri	Locked Wheel Skid Trailer	Police Escort	None	Lights
Nebraska	Locked Wheel Skid Trailer			Signs Lights
Nevada	Locked Wheel Cox Skid Trailer Law	None None	None None	

TABLE E-4
SAFETY FEATURES OF FRICTION MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Traffic Control Requirements: High Traffic Facilities	Traffic Control Requirements: Low Traffic Facilities	Other Safety Features
New Hampshire	Locked Wheel Skid Trailer			Pilot Vehicles Strobe
New Jersey	Locked Wheel Skid Trailer	None	None	Lights Signs
New York	Locked Wheel Skid Trailer	None	None	
North Carolina	Locked Wheel Skid Trailer	None	None	Signs Lights
Ohio	Locked Wheel Skid Trailer			Lights
Oklahoma	Locked Wheel Skid Trailer			
Oregon	Locked Wheel Skid Trailer			Lights Signs
Pennsylvania	Locked Wheel Skid Trailer	Police Sometimes	None	
South Carolina	Locked Wheel Skid Trailer	None	None	Yellow Beacons
South Dakota	Locked Wheel Skid Trailer			Lights
Tennessee	Locked Wheel Skid Trailer	None	None	Lights
Texas	Locked Wheel Skid Trailer	None	None	Lights
Utah	Mu-Meter	None	None	
Virginia	Locked Wheel Skid Trailer	None	None	Lights
Washington	Locked Wheel Skid Trailer	None	None	Lights
West Virginia	Locked Wheel Skid Trailer	None	None	
Wisconsin	Locked Wheel Skid Trailer		None	Police At Intersection
Wyoming	Locked Wheel Skid Trailer	None	None	

TABLE E-5
MAINTENANCE REQUIREMENTS AND COSTS OF FRICTION MEASURING EQUIPMENT

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency of Repair	Approximate Costs	Comments
Alabama	Locked Wheel Skid Trailer	Brake Pads	As Needed	Unknown	Truck or Two Vehicle Replaced After 8 Years
		Water Pump	As Needed	575.00	
		Skid Tire	As Needed	125.00	
Arizona	Mu-Meter				
Arkansas	Locked Wheel Skid Trailer	Vehicle & Electronic Components Need Constant Repair Due to Age of Equipment	Double the Initial Cost		
California	Locked Wheel Skid Trailer	Electronic	Varies	1,200.00	
		Trailer Brakes	6 Weeks	800.00	
		Water Pump	10 Weeks	500.00	
		Truck Brakes	12 Weeks	500.00	
		Truck Engine	9 Mo-3 Yrs.	1,000-2,000	
		Truck Transmission	2 Yrs.	600.00	
Connecticut	Locked Wheel Skid Trailer	Brakes, Battery, Alternative Water Strainer			
Delaware	Locked Wheel Skid Trailer	Electric Trailer Brakes	Monthly	50.00	
		Recorder	Annual	40.00	
		Water Pump/Clutch	2-3 Yrs.	300.00	
		Trailer Tires	Monthly	150.00	
Florida	Locked Wheel Skid Trailer	Transducer	Varies	800-1,200	
		Wheel Bearings, Brake Pads, Wheel, Tachometer, Electronic Pads	Varies		
Georgia	Locked Wheel Skid Trailer	Very Little with Travler Most Maintenance on Tow Vehicle			
Hawaii	Locked Wheel Skid Trailer	Data Logger	2 Yrs.	200.00	
		Gear Belt on Water Pump	2 Yrs.	50.00	
		Transducer	2 Yrs.	500.00	
		Muffler	2 Yrs.	120.00	
Idaho	Locked Wheel Skid Trailer	Brake System	7 Yrs.	1,200.00	
		Water Valves	2 Yrs.	600.00	
		Water Pump	7 Yrs.	900.00	
		Automate System	7 Yrs.	6,000.00	
Illinois	Locked Wheel Skid Trailer	Brakes, Water Pump, Recording Equipment Tow Truck			
Indiana	Locked Wheel Skid Trailer	Brakes & Tires	Bimonthly	330.00	
		Truck Tires	Annually	400.00	
		Strain Gauges	Biannually	250.00	
		Oil & Lube	Biweekly	10.00	
Iowa	Locked Wheel Skid Trailer	Trailer Air Shocks	Annually	150.00	
		Trailer Disc Brakes	Annually	450.00	
		Trailer Transducers	Biannually	2,500.00	
		Trailer Water Pump	Biannually	400.00	
		Towing Vehicle	Annually	500.00	
Kansas	Locked Wheel Skid Trailer	Wheel Bearings	Annually	200.00	
		Tires	10 Days	2,000.00	
Kentucky	Locked Wheel Skid Trailer				
Louisiana	Locked Wheel Skid Trailer British	New Machine			
Maryland	Locked Wheel Skid Trailer				

TABLE E-5
MAINTENANCE REQUIREMENTS AND COSTS OF FRICTION MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency of Repair	Approximate Costs	Comments
Nebraska	Locked Wheel Skid Trailer				
Nevada	Locked Wheel Cox	Generator	Annually		
	Skid Trailer Law	Electrical Component	Annually		
		Hydraulic Brace System			
New Hampshire	Locked Wheel Skid Trailer	Rent From State of Maine			
New Jersey	Locked Wheel Skid Trailer	No Special Problem			
New York	Locked Wheel	Electronic	Often	100.00	
	Skid Trailer	Mechanical	Occasional	400.00	
North Carolina	Locked Wheel	Circuits	Constraint		
	Skid Trailer	Air Compressor	4 Months	300.00	
		Power Generator	4 Months	300.00	
		Vehicle Alternator	3 Months	150.00	
Ohio	Locked Wheel	Trailer Bracing System	Annually	100.00	
	Skid Trailer	Electronical	Annually	300.00	
		Wheel Transducers	4 Years	1,000.00	
		Transducers Cable Connectors Cleaning	Biannually		
Oregon	Locked Wheel	Axle Bearing	Annually	300.00	
	Skid Trailer	Electronical	4 Months	5,600.00	
		Brakes	Biannually	1,000.00	
Pennsylvania	Locked Wheel	Transducer	Annually		
	Skid Trailer	Wheel Bearings	2 Years	200.00	
		Brakes	Annually	66.00	
		Preventive Maintenance	Monthly	25.00	
South Carolina	Locked Wheel Skid Trailer		Annually	1,000.00	
South Dakota	Locked Wheel	Air Compressor	4 Years	200.00	
	Skid Trailer	DC-AC Inverter	3 Years	50.00	
		Water Pump	3 Years	150.00	
		Circuit Boards	2 Years	50.00	
		Engine Replacement	7 Years	1,200.00	
Tennessee	Locked Wheel	Computer, Tires, Towing Vehicle		1,000.00	
	Skid Trailer	Calibration		10,000.00	
Texas	Locked	Electronics	3 Months	200.00	
	Skid Trailer	Mechanical	12 Months	250.00	
Utah	Mu-Meter	Electrical	3 Months	400.00	
		Mechanical	2 Months	800.00	
Virginia	Locked Wheel Skid Trailer	Electronics, Brakes System, Etc.		4,800.00	
Washington	Locked Wheel Skid Trailer	Tires		100.00	
Wyoming	Locked Wheel	Trailer Wheel Bearings	Annually	500.00	
	Skid Trailer	Towing Vehicle	Annually	1,500.00	

APPENDIX F

RESULTS FROM QUESTIONNAIRE ON ROUGHNESS MEASURING EQUIPMENT (JUNE 1983)

TABLE F-1
GENERAL CHARACTERISTICS OF ROUGHNESS MEASURING EQUIPMENT

		Uses of Equipment				
Public Agency	Equipment Identification	Input To Network Management	Input To Network Management	Other	Data Processing Feature	Calibration Requirements
Alabama	Modified BPR Roughometer			Statewide Survey Every Two Years	Recorded on Apple II Micro & Processed By Apple III Micro	Frequently With Pavement Test Sections Periodically With Chloe
Alaska	Mays Meter			Planning	Strip Recorder	None Used
Arizona	Mays Meter	Yes	Yes		Paper Tape Printed Results	PVT Sections Artificial Reference Surfaces
Arkansas	Mays Meter	Yes	Sometimes		Magnetic & Paper Tape	When Tires Are Replaced
California	California Ride Meter	Yes	Yes	Research		One Day Per Month
Florida	Mays Meter	Yes		PVT Research Condition Survey	Hand Code for Computer	Yearly On TEst Sections Against Chloe
Georgia	Mays Meter	No	Yes	Construction Smoothness Control	Digital Unit	Twice Per Month
Hawaii	Cox Roadmeter	Yes	Yes		Cassette	Odometer Displacement
Idaho	Ultrasonic Roadmeter	Yes			TI 990 to HP-85 to IBM 4180	Auto Null Dial Indicator Daily Tire Pressure
Illinois	BPR Roughometer	Yes	Yes	Research		Monthly
Indiana	Ultrasonic Roadmeter	Yes	Yes		On Board Data Summaries	Once Per Month On Standard Surfaces Once Per Day On Measured Mile
Iowa	Roadmeter	Yes		Research	None	Correlated Annually to Chloe on 50 Test Sections Weekly Checks
Kansas	Mays Meter	Yes	Yes		Mag Tape & Plexus P40 Computer	Bump Track
Kentucky	Mays Meter Profilometer	Yes	Yes	 Correlate Mays Meter		 Extensive

TABLE F-1
GENERAL CHARACTERISTICS OF ROUGHNESS MEASURING EQUIPMENT (Continued)

		Uses of Equipment				
Public Agency	Equipment Identification	Input To Network Management	Input To Network Management	Other	Data Processing Feature	Calibration Requirements
Louisiana	Mays Meter	Sometimes	Sometimes			Control Sections GM Profilometer
	Profilometer	Sometimes	Sometimes	PCC Pavement		
	Rolling Straight Edge	Sometimes	Sometimes	New Construction		Every Job Site
Maryland	Mays Meter	Yes	Yes			Against Known Roadways
Massachusetts	Mays Meter	Yes	Yes		None	Correlate To Standard Pavement
Michigan	Rapid Travel Profilometer	Yes	Sometimes	Source of PVT Roughness	Analog Digital	
Minnesota	PCA Meter	Yes	Yes		None	Annually With Panel Test Roads Weekly
Missouri	Chloe Profilometer		Sometimes	Research	Auto Calculation of Slope Variance	Slope Transducer Data Accumulation
Nebraska	Roadmeter	Yes	No		None	Twice Annually on Test Loop
Nevada	Ridemeter	Yes			None	
	Ultrasonic	Yes			None	
New Hampshire	Mays Meter	Sometimes	Sometimes		Manual	None
New Jersey	Mays Meter	Yes	Yes		Cassette	Speed & Distance Monthly
New York	APRRTS	Yes	Yes		Computerized	Bench Calibration PVT Test Sections
Ohio	Mays Meter	Sometimes	Yes		Solid State Memory	Weekly
	SDP	Sometimes	Yes		PDP 11/34 (DEC) With Tape Drive	Daily
Oklahoma	Mays Meter	No	Sometimes	Research	Digital Readout	Calibrated To Texas Surface Dynamics Profilometer
Oregon	Roadmeter	Yes	No	Smoothness Quarterly	Manually	None
Pennsylvania	Mays Meter	Sometimes	Yes		Paper Chart Cassette	GM Profilometer Speed, Distance
South Carolina	Mays Meter	Sometimes	Sometimes	Research	None	6 Months or When Change Tiring Shocker

TABLE F-1
GENERAL CHARACTERISTICS OF ROUGHNESS MEASURING EQUIPMENT (Continued)

		Uses of Equipment				
Public Agency	Equipment Identification	Input To Network Management	Input To Network Management	Other	Data Processing Feature	Calibration Requirements
South Dakota	Profilometer	Yes	Yes		Automated Into PMS	None
Tennessee	Mays Meter		Yes		Manual	Weekly
Texas	Mays Meter SDP	Yes No	Yes Yes	Research	Keypunched Computer	With Surface Dynamics Profilometer Distance
Utah	Roadmeter	Yes	Yes		Printout	Physical
Vermont	Mays Meter	Yes	Yes		None	
Virginia	Mays Meter	Sometimes	Yes	Construction Research		PVT Test Sections
Washington	Roadmeter	Yes	Yes	Overlay Project Smoothness	None	None
West Virginia	Mays Meter Profilometer	Sometimes Sometimes	Sometimes Seldom		Computer	Calibrated Against Profilometer
Wisconsin	PCA Meter	Yes	Sometimes	Research	Auto	Yearly Checked Weekly
Wyoming	Mays Meter	Yes	Yes		None	None

TABLE F-2
OPERATING CHARACTERISTICS OF ROUGHNESS MEASURING EQUIPMENT

Public Agency	Equipment Identification	Operating Forward Speed MPH		Data Points Per Day		Lane Miles Of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Alabama	Modified BPR Rough- ometer	40				150				150	
Alaska	Mays Meter	50	5			400	50	Continuous		15	
Arizona	Mays Meter	45				200				60	
Arkansas	Mays Meter	40	30-35			260	195-360			200	
California	California Ride Meter	50		150		150		1		240	
Florida	Mays Meter	40 Depends on Speed Limit	30-50								
Georgia	Mays Meter	50									
Hawaii	Roadmeter	45		42		100		0.4		42	
Idaho	Ultrasonic Roadmeter	50	25-60			200	150-300	2	1-10	100	
Illinois	BPR Roughometer	20									
Indiana	Roadmeter	50		150	100-200	150	100-200	1		110	90-130
Iowa	Roadmeter	50		30		150		0.20		110	
Kansas	Mays Meter	50		3000		300	250-325	10		100	
Kentucky	Mays Meter Profilometer	 40									
Louisiana	Mays Meter Profilographs Rolling Straight Edge	50 2 2		100 20 20		20 10 10	5-100	5 2 2		100 30 30	
Maryland	Mays Meter	35	20-40			100	10-200			120	65-185
Massachusetts	Mays Meter	40				50	20-100			100	70-200
Michigan	Rapid Travel	51	17-51			50	0-300	1572		150	
Minnesota	PCA Meter	50	25-50							20	
Missouri	Chloe	2		40000		4		10000		10	

TABLE F-2
OPERATING CHARACTERISTICS OF ROUGHNESS MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Operating Forward Speed MPH		Data Points Per Day		Lane Miles Of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Nebraska	Roadmeter	50	30-55	200	100-300	200	200-300	1	1-2	200	150-300
Nevada	Ridemeter	50		100	50-150	100	50-150	1		65	45-75
	Ultrasonic	50		225	150-300	225	150-300			85	65-105
New Hampshire	Mays Meter	Legal Speed								30	0-60
New Jersey	Mays Meter	40		2000	1605-2400	100	80-120	20		120	
New York	APRRTS					130				130	
Ohio	Mays Meter	50				150	100-200	5			
	SDP	50	20-50			80	20-100			180	
Oklahoma	Mays Meter	50				200				15	10-20
Oregon	Roadmeter	50	35-55	135	100-150	135		1		110	100-120
Pennsylvania	Mays Meter	40	25-40	500	150-1500	50		10		150	
South Carolina	Mays Meter	50				200	100-300			125	100-150
South Dakota	Profilometer	55	25-70	1410[6]		200		5280		50	
Tennessee	Mays Meter	50				10				50	
Texas	Mays Meter	50	48-52			200	160-240			75	50-100
	SDP	20	18-22			10	5-15			50	25-75
Utah	Roadmeter		30-55	250	200-300	250	200-300	1		150	125-175
Vermont	Mays Meter	50				200		20		15	
Virginia	Mays Meter	55	25-55			30	0-65			85	0-200
Washington	Roadmeter	50	25-50	300	200-350	300	200-350	1	1-4	65	40-85
West Virginia	Mays Meter	45						6		50	
	Profilometer	50								100	
Wisconsin	PCA Meter	50		240		240		1		110	
Wyoming	Mays Meter	50		250		250		1		85	

TABLE F-3
FIRST COSTS AND OPERATING COSTS OF ROUGHNESS MEASURING EQUIPMENT

Public Agency	Equipment Identifications	Purchase Price	Operating Costs: Per Data Point Average	Operating Costs: Per Data Point Range	Operating Costs: Per Lane Mile of Pavement Average	Operating Costs: Per Lane Mile of Pavement Range	Manpower: No.	Manpower: Operational Qualifications	Manpower: Repair & Maintenance Qualifications
Alabama	Modified BPR Roughometer	43,700 In 1982 Vehicle, Microcomputer & Roughometer					2	Knowledge of Roughometer & State Network of Highways	Lubrication Points & Roughometer
Alaska	Mays Meter	12,000					2	Driver Familiar With Road Network	Mechanical Ability
Arizona	Mays Meter	5,000	4.00		4.00		2	Limited Knowledge of Mechanical & Electrical Equipment	Limited Knowledge of Mechanical & Electrical Equipment
Arkansas	Mays Meter				0.85		1	Driver Familiar With Equipment	Electronics
California	California Ride Meter	13,600	4.00				1	1 to 3 Weeks of Training	
Florida	Mays Meter						2	Electronic & Mechanical	Electronic & Mechanical
Georgia	Mays Meter	6,200							
Hawaii	Roadmeter	28,000	9.50		3.80	3.30-4.30	2	Technician	
Idaho	Ultrasonic Roadmeter	60,000	3.00		3.00		2	Technician	Electronic
Illinois	BPR Roughometer						2		Electronic
Indiana	Roadmeter	14,200	0.67	0.50-1.00	0.67	0.50-1.05	1		Electronic & Mechanical
Iowa	Road Meter	1,200 In 1975	26.00		5.20		2	Technician	Electronics
Kansas	Mays Meter	7,846 Plus Tow Vehicle	0.35		3.50		2	Technician	BSEGS
Kentucky	Mays Meter Profilometer						1 2	Technician Technician	Technician Electronic
Louisiana	Mays Meter Profilograph Rolling Straight Edge	8,000 8,270 2,500	1.38 9.90 11.00		6.91 19.80 22.00		2 3 3	 Technician Technician	Electronic Mechanical Mechanical
Maine		2,441			0.41		2	Technician	Electrical & Mechanical

TABLE F-3
FIRST COSTS AND OPERATING COSTS OF ROUGHNESS MEASURING EQUIPMENT (Continued)

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile of Pavement				
Public Agency	Equipment Identifications	Purchase Price	Average	Range	Average	Range	No.	Operational Qualifications	Repair & Maintenance Qualifications
Maryland	Mays Meter								
Massachusetts	Mays Meter	17,000			15.00		2	Mechanical & Electrical	Mechanical & Electrical
Michigan	Rapid Travel Profilometer						3	Technician	Mechanical & Electrical
Minnesota	PCA Meter	500					2	Technician	
Missouri	Chloe Profilometer	6,000 In 1964			150.00		5	Electronics	Electronic
Nebraska	Roadmeter						2	Technician	Technician
Nevada	Ridemeter	1,500 Plus Car	2.87	1.91-5.74	2.87	1.91-5.74	2	Technician	Technician
	Ultrasonic	7,800 Plus Car	1.04	0.78-1.56	1.04	0.78-1.56	2	Technician	Technician
New Hampshire	Mays Meter	3,000 Plus Car			10.00		3	Technician	
New Jersey	Mays Meter	25,000					2	Technician	Electrical & Mechanical
Ohio	Mays Meter	1,500			7.00	6-9	2	Technician	
	SDP	200,000			8.00		2	Basic Computers	Electronic
Oklahoma	Mays Meter	1,100 In 1971					2		Electronic
Oregon	Roadmeter		1.65		1.65				
Pennsylvania	Mays Meter	20,000			8.00		2	Technician	Electronic
South Carolina	Mays Meter	18,000			0.75	0.60-1.50	2	Technician	Mechanical
South Dakota	Profilometer	30,000			2.00		2	Technician	Electronic
Tennessee	Mays Meter	7,000			0.21		1	Technician	
Texas	Mays Meter	10,000 With Trailer	0.18		0.93	0.87-0.97	2	Technician	Technician
	SDP	216,000				1.50-2.50	2	Technician	Technician
Utah	Roadmeter	10,000 Plus Host Vehicle	0.60	0.40-0.80	0.60	0.40-0.80	2	Technician	Electronic

TABLE F-3
FIRST COSTS AND OPERATING COSTS OF ROUGHNESS MEASURING EQUIPMENT (Continued)

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile of Pavement				
Public Agency	Equipment Identifications	Purchase Price	Average	Range	Average	Range	No.	Operational Qualifications	Repair & Maintenance Qualifications
Vermont	Mays Meter	1,060 Meter 8.000 Vehicle	1.75		1.75		2	Technician	Electronic
Virginia	Mays Meter	2,000 Meter Only			6.00	2-10	1	Technician	Electrical & Mechanical
Washington	Roadmeter	8,500	0.95	0.76-1.26	0.95	0.76-1.26	2	Engineer, Technician	
West Virginia	Mays Meter Profilometer	1,074-1663 200,000			1.00 1.12		1 2	 Electronic	Electronic Electronic
Wisconsin	PCA Meter		2.00		2.00		2	Technician	Electronic & Mechanical
Wyoming	Mays Meter		1.50		1.50		2	Technician	

TABLE F-4
SAFETY FEATURES OF ROUGHNESS MEASURING EQUIPMENT

Public Agency	Equipment Identification	Traffic Control Requirements: High Traffic Facilities	Traffic Control Requirements: Low Traffic Facilities	Other Safety Features
Alabama	Modified Bar Roughometer	None	None	Rotary Lights And Flashing Sign On Vehicle
Alaska	Mays Meter	None	None	None
Arizona	Mays Meter	None	None	None
Arkansas	Mays Meter	None	None	Caution Sign On Vehicle Strobe Light On Trailer And Vehicle
California	California Ride Meter	None	None	Lights Warning Sign Safety Belts
Florida	Mays Meter			Strobe Lights On Traielrs And Tow Vehicle
Georgia	Mays Meter	None	None	
Hawaii	Roadmeter	Hazard Warning Lights	None	
Idaho	Ultrasonic Roadmeter	Strobe		
Illinois	BPR Roughometer	Follow Vehicle	None	
Indiana	Roadmeter	None	None	
Iowa	Roadmeter	None	None	
Kansas	Mays Meter	None	None	
Kentucky	Mays Meter Profilometer	None	None	
Louisiana	Mays Meter Profilograph Rolling Straight	None	None	 Flagman, Arrow, Lights Flagman, Arrow, Lights
Maryland	Mays Meter	Follow Vehicle	None	
Massachusetts	Mays Meter	None	None	Strobe Lights
Michigan	Rapid Travel Profilometer	None	None	
Minnesota	PCA Meter	None	None	
Missouri	Chloe Profilometer			Signs, Flagmen, Arrow Board
Nebraska	Roadmeter	None	None	
Nevada	Ridemeter Ultrasonic	None None	None None	
New Hampshire	Mays Meter	None	None	
New Jersey	Mays Meter	None	None	Lights, Signs
New York	APRRTS	None	None	
Ohio	Mays Meter SDP	None None	None None	
Oklahoma	Mays Meter			
Oregon	Roadmeter			Signs On Vehicle
Pennsylvania	Mays Meter	Police Sometimes	None	

TABLE F-4
SAFETY FEATURES OF ROUGHNESS MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Traffic Control Requirements: High Traffic Facilities	Traffic Control Requirements: Low Traffic Facilities	Other Safety Features
South Carolina	Mays Meter	None	None	Beacons
South Dakota	Profilometer	None	None	
Tennessee	Mays Meter	Operate In Off-Peak Hours	None	
Texas	Mays Meter	None	None	
	SDP			Cones, Signs, Flagmen
Utah	Roadmeter	None	None	
Vermont	Mays Meter	None	None	
Virginia	Mays Meter	None	None	
Washington	Roadmeter	None	None	
West Virginia	Mays Meter	None	None	
	Profilometer	None	None	
Wisconsin	PCA Meter	None	None	Lights, Signs
Wyoming	Mays Meter	None	None	

TABLE F-5
MAINTENANCE REQUIREMENTS AND COSTS OF ROUGHNESS MEASURING EQUIPMENT

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency of Repair	Approximate Costs
Alabama	Modified BPR Roughometer	Dash Pots	As Needed	$500.00
		Tires	As Needed	$125.00
		Lubrication of Roughometer	Weekly	Unknown
		Fluid In Dash Pots	Before Each Use	Unknown
Alaska	Mays Meter	Shocks On Trailer	Annually	$ 30.00
		Springs	Every 3 Years	$300.00
Arizona	Mays Meter			
Arkansas	Mays Meter	Wiring	6 Months	Negligible
	Profilometer	Electrical and Mechanical		High
Florida	Mays Meter	Photo Cell Assembly	6 Months	
		Shocks On Trailer	6 Months	
Georgia	Mays Meter	Shocks, Tires		
Hawaii	Roadmeter			
Idaho	Ultrasonic Roadmeter	New Shocks	Annually	$150.00
		Sensor Wire	6 Months	$ 10.00
Illinois	BPR Roughometer			
Indiana	Roadmeter	Translating Cable	Biweekly	$ .2.50
		Tires	Bimonthly	$100.00
		Shocks	Semiannually	$ 50.00
		Oil and Lube	Biweekly	$ 10.00
Iowa	Roadmeter	Wires	Annually	$ 50.00
		Counters	Annually	$100.00
		Vehicle	Annually	$100.00
Kansas	Mays Meter	Shocks		
Louisiana	Mays Meter	Cable, Film Strip, Transmitter Alignment		
	Profilograph	String In Drive Recorder	2 Months	$ 20.00
	Rolling Straight Edge	Vertical Gear Shaft	Annually	$ 35.00
Maryland	Mays Meter			
Massachusetts	Mays Meter	Mechanical and Electrical	Monthly	$2-500.00
Michigan	Rapid Travel Profilometer	Mechanical and Electrical		
Minnesota	PCA Meter			
Missouri	Chloe Profilometer	Wheel Bearings	2 Years	$400.00
		Tires	2 Years	$400.00
		Calibration	Semiannually	$300.00
Nebraska	Roadmeter			
New Hampshire	Mays Meter	Vehicle Suspension System and Tires		
New Jersey	Mays Meter			
Ohio	Mays Meter	Shocks, Tires	Annually	$600.00
	SDP	New Equipment		
Oklahoma	Mays Meter	IC Chips	3 Years	$ 5.00
		Electronic		
Oregon	Roadmeter	PCA Roadmeter	3 Months	$200.00
		Car Mechanical Problems	2 Months	$100.00

TABLE F-5
MAINTENANCE REQUIREMENTS AND COSTS OF ROUGHNESS MEASURING EQUIPMENT (Continued)

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency of Repair	Approximate Costs
Pennsylvania	Mays Meter	Recorder	Monthly	$ 12.00
		Cable	Annually	$ 15.00
		Mylar Film Strip	Annually	$ 10.00
South Carolina	Mays Meter	Shocks, Tires Tow Vehicle	Annually	$800.00
Tennessee	Mays Meter		Annually	$500.00
Texas	Mays Meter	Tires and Suspension	2 Years	$150.00
	SDP	Following Wheel	2 Years	$500.00
		Electronics	12 Months	$800.00
		Mechanical	6 Months	$100.00
Utah	Roadmeter	Minor		Minimal
Vermont	Mays Meter			$100.00
Virginia	Mays Meter	Broken Cable	6 Months	$ 25.00
		Voltage Deficiency	Rare	$100.00
		Odometer Malfunction		$100.00
Washington	Roadmeter	None		
Wisconsin	Locked Wheel Skid Trailer	Shock Absorber	10,000 Miles	$ 50.00
		Front End Alignment	6 Months	$ 50.00

APPENDIX G

RESULTS FROM QUESTIONNAIRE ON TRAFFIC VOLUME AND WEIGHT EQUIPMENT (JUNE 1983)

TABLE G-1
GENERAL CHARACTERISTICS OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT

Public Agency	Equipment Identification	Uses of Equipment			Data Processing Feature	Calibration Requirements
		Input To Network Management	Input To Network Management	Other		
Alabama	Unitech Weigh-In-Motion			Loadometer Truck Weight Enforcement	Print Out of Vehicle Weight, Speec, Axle Spacing, Etc.	With Known Truck Weight
Arizona	Traffic Counter, Model GR0328 Golden River	Sometimes	Sometimes		Modern to Mainframe	None
	Traffic Counter, Model MR1038 Streeter-AMET	Yes	Yes		Tape Recording	
	Traffic Counter, Model JR160 Streeter-AMET	Yes	Yes		Electromechanical Counter	
Arkansas	Portable Counters	Yes	Yes	Traffic Counting Program		Minor Adjustment
	Fixed Counters	Yes	Yes	Vehicle Classification & Speed	Mag & Paper Tape	Each Time Data Retrieved
	Portable Scale	Yes	Yes			Annually
Delaware	Portable Counters	Yes	Yes	Planning, Design, Research		
	Fixed Counters	Yes	Yes	Planning, Design, Research		
	Weigh-In-Motion	Sometimes	Yes	None		
	Portable Scales	Sometimes	Yes	None		
	Permanent Weigh Station	Sometimes	Yes	None		
Hawaii	Traffic Counters				Teletype Computer	
	Portable Scales				Manual Coding	Annually
Idaho	Portable Counter	Sometimes	Yes		None	None
	Fixed Counter-Telac	Sometimes	Yes		Mag Tape	None
	Weigh-In-Motion	Yes	Yes		Keypunch & Cartridge Tape	
	Permanent Weigh Station	Sometimes	Sometimes		Keypunch for Computer	
	Fixed Counter Streeter	Sometimes	Yes		Keypunch	None
Illinois	Portable Counters Classified	Yes	Yes		Paper Tape	None
	Fixed Counters	Yes	Yes		Paper Tape	None
	Portable Scales	No	No	Enforcement	None	80 Days
	Permanent Weigh Station	Yes	Yes	Enforcement	None	120 Days
Indiana	Portable Counters	Yes	Yes		Auto Keypunch	
	Fixed Counters	Yes	Yes		Punch or Print Tape	
	Portable Scales	Yes	Yes		Coding	Annually or Hydro-Press

TABLE G-1
GENERAL CHARACTERISTICS OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT (Continued)

		Uses of Equipment				
Public Agency	Equipment Identification	Input To Network Management	Input To Network Management	Other	Data Processing Feature	Calibration Requirements
Iowa	Portable Counter 160 JR	Yes	Yes		Keypunch	
	Portable Counter - MRWI 1B	Yes	Yes		Manually	
	Fixed Counter	Yes	Yes		Paper Tapes	
	Portable Scales	Yes	Yes		Manual Keypunched	Certified
Louisiana	Weigh-In-Motion	Sometimes	Yes	Research	Microcomputer	Electronic Balance
Missouri	Portable Counters	Yes	Yes			
	Fixed Counters	Yes	Yes			
	Portable Scales	Yes	Yes			
	Permanent Weigh Station			Enforcement		
Nebraska	Portable Counters	Yes	Yes			
	Fixed Counters	Yes	Yes			
	Permanent Weigh Station	Yes	Yes	Enforcement		Quarterly
New Jersey	Portable Counters	Yes		Design	Cassette	
	Portable Scales	Yes		Enforcement		
North Carolina	Portable Scales	Yes	Yes	Enforcement		Annually
	Permanent Weigh Station	Yes	Yes	Enforcement	Micro-Processor	Annually
Ohio	Portable Counters	Yes	Yes			
	Fixed Counters	Yes	Yes			
	Weigh-In-Motion	No	No	Research	Computer	
	Portable Scales	Yes	Yes			
Oklahoma	Portable Counters	Yes	Yes			
	Fixed Counters Telemetry	Yes	Yes		Automated	
	Weigh-In-Motion					
	Portable Scale					

TABLE G-2
OPERATING CHARACTERISTICS OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT

Public Agency	Equipment Identification	Operating Foreward Speed MPH		Data Points Per Day		Lane Miles Of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Alabama	Unitech									160	
	Weigh-In-Motion										
Arizona	Traffic Counter 0328									2-365	
	Golden River										
	Traffic Counter 1038										
	Streeter AMET										
	Traffic Counter 160										
	Streeter AMET										
Arkansas	Portable Counters									200	
	Fixed Counters									365	
	Portable Scales									40	
Delaware	Portable Counters										
	Fixed Counters										
	Weigh-In-Motion										
	Portable Scales										
	Permanent Weigh Station										
Hawaii	Traffic Counters									200	
	Portable Scales										
Idaho	Portable Counters							24			
	Fixed Counters TELEC			24						365	
	Weigh-In-Motion	3	0-5								
	Permanent Weigh Station										
	Fixed Counters-Streeter							24		365	
Illinois	Portable Counters Classifiers			1						80	60-120
	Fixed Counters			1						365	
	Portable Scales									150	
	Permanent Weigh Station									240	200-260
Iowa	Portable Counters			24						100	
	Fixed Counters			24						365	
	Portable Scales										
Kansas	Portable Counter 160JR			1							
	Portable Counter MR101/B			1						50	
	Fixed Counter			1						365	
	Portable Scales			1						15	
Louisiana	Weigh-In-Motion									8	
Missouri	Portable Counters									230	
	Fixed Counters									365	
	Portable Scales									3	
	Permanent Weigh Station									300	

TABLE G-2
OPERATING CHARACTERISTICS OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT (Continued)

Public Agency	Equipment Identification	Operating Foreward Speed MPH		Data Points Per Day		Lane Miles Of Pavement Per Day		Data Points Per Lane Mile		Days Per Year Equipment Utilized	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
New Jersey	Portable Counters										
	Portable Scales									90	
North Carolina	Portable Scales			39	9-49			251			
	Permanent Weigh Station			1,384	234-5034			25			
Ohio	Portable Counters			34	30-69			250			
	Fixed Counters			10				365			
	Weigh-In-Motion			960							
	Portable Scales										
Oklahoma	Portable Counters										
	Fixed Counters										
	Weigh-In-Motion										
	Portable Scales										

TABLE G-3
FIRST COSTS AND OPERATING COSTS OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile Of Pavement			Operational	Repair & Maintenance
Public Agency	Equipment Identification	Purchase Price	Average	Range	Average	Range	No.	Qualifications	Qualifications
Alabama	Unitech Weigh-In-Motion	75,000 Excluding Site Installation	80,000/Yr.				1	Computer Oriented, Electronic Trained	Computer Repair Training, Electronic Expert
Arizona	Traffic Counter 0328 Golden River	200.00-2,000					1	Electronics	Electronics
	Traffic Counter 1038 Streeter AMET	2,000						Mechanical & Electronics	Mechanical & Electronics
	Traffic Counter 160 Streeter AMET	225						Mechanical & Electrical	Mechanical & Electronics
Arkansas	Portable Counters	100.00					1		
	Fixed Counters	1,500					1		Electronics
	Portable Scales	2,970					8	None	
Delaware	Portable Counters	1,500	3.50/Mo.				1	Mechanical	Mechanical
	Fixed Counters	7,500	10.00/Mo.						
	Weigh-In-Motion	85,000					3	Vehicle Laws	Manufacturer Repair
	Portable Scales	23,170 In 1978					3		
	Permanent Weigh Station	110,000					3		Manufacturer Repair
Hawaii	Traffic Counters	900/Stevens 3,000/Telac					1		Electronic & Mechanical
	Portable Scales	7,000-12,000					4-7		Electrical
Idaho	Portable Counter	4,500					1	Mechanical	Electronic
	Fixed Counter Telec	3,500							Mechanical & Electronics
	Weigh-In-Motion	80,000					3	Electronic & Mechanical	
	Permanent Weigh Station						1	No Special Skills	
	Fixed Counter-Streeter	985							
Illinois	Portable Counter Classifier	2,000	30.00				2	Programming	Electronic
	Fixed Counter	1,400	2.00				1		Electronic
	Portable Scales	25,000					2		Electronic
	Permanent Weigh Station		1.00	0.75-2.90			1		Electronic
Iowa	Portable Counters	900					1		Electronics
	Fixed Counter	1,200-2,500							Electronics
	Fixed Scales	300							
Kansas	Portable Counters 160 JR	160	10.00				1	Technician	Electronics
	Portable Counters MR101/B	900					1	Technician	Electronics
	Fixed Counter	1,078	150.00				0		Electronics
	Portable Scales	625					1		
Louisiana	Weigh-In-Motion	50,000					2	Technician	Electronics

TABLE G-3
FIRST COSTS AND OPERATING COSTS OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT (Continued)

			Operating Costs				Manpower		
			Per Data Point		Per Lane Mile Of Pavement		Operational		Repair & Maintenance
Public Agency	Equipment Identification	Purchase Price	Average	Range	Average	Range	No.	Qualifications	Qualifications
Missouri	Portable Counters	1,375	33.00	30.00-36.00			1	Mechanical	Electronics
	Fixed Counters	1,335	37.00				1	Mechanical	Electronics
	Portable Scales						1		Mechanical
	Permanent Weigh Station						1		
Nebraska	Portable Counters	1,345							
	Fixed Counters	980	9.60		2.64		4	Technician	Electronics
	Portable Weigh Station	215,000						Police, Technician	
New Jersey	Portable Counters	800	150.00						Manufacturer
	Portable Scales	1,615					5	Minimal	
North Carolina	Portable Scales	1,500	30.00	5.00-50.00			1	Police	Technician
	Permanent Weigh Station	30,000	0.46	0.13- 2.73			8	Police	Technician
Ohio	Portable Counters	90-850					1	Technician	Mechanical
	Fixed Counters	600					1		
	Weigh-In-Motion	80,000 + Vehicle					2	Technician	
	Portable Scales						5	Electrical & Mechanical	
Oklahoma	Portable Counters	100-1,000							
	Fixed Counters-Telemetry	100,000							
	Weigh-In-Motion	48,000 + Van							
	Portable Scales								

TABLE G-4
SAFETY FEATURES OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT

Public Agency	Equipment Identification	Traffic Control Requirements: High Traffic Facilities	Traffic Control Requirements: Low Traffic Facilities	Other Safety Features
Alabama	Unitech Weigh-In-Motion	None	None	None
Arizona	Traffic Counter 0328	None	None	
	Golden River			
	Traffic Counter 1038			
	Streeter AMET			
	Traffic Counter 160			
	Streeter AMET			
Arkansas	Portable Counters			
	Fixed Counters			
	Portable Scales	Signs & Pylons, Police	Signs & Pylons, Police	
Delaware	Portable Counters			
	Fixed Counters			
	Weigh-In-Motion			
	Portable Scales			
	Permanent Weigh Station			
Hawaii	Traffic Counters	None	None	
	Portable Scales	Police, Signs	Police, Signs	
Idaho	Portable Counters	None	None	
	Fixed Counter TELEC	None	None	
	Weigh-In-Motion			Signs, Cones, Flagman
	Permanent Weigh Station			Stop-Go Lights
	Fixed Counter - Streeter			
Iowa	Portable Counters			
	Fixed Counters			
	Portable Scales			
Louisiana	Weigh-In-Motion	Lane Closed	Lane Closed	
Missouri	Portable Counters			
	Fixed Counters			
	Portable Scales			
	Permanent Weigh Station			
North Carolina	Portable Scales			Trucks Pull Off Highway
	Permanent Weigh Station			Trucks Pull Off Highway
Ohio	Portable Counters			
	Fixed Counters			
	Weigh-In-Motion		None	High Speed Measurement
	Portable Scales			

TABLE G-5
MAINTENANCE REQUIREMENTS AND COSTS OF TRAFFIC VOLUME AND WEIGHT EQUIPMENT

Public Agency	Equipment Identification	Problem Requiring Maintenance	Frequency Of Repair	Approximate Costs	Comments
Alabama	Unitech Weigh-In-Motion	Load Cell	Infrequent		No Emergency Repairs ecessary
Arizona	Traffic Counter 0328	Telco Connection	Monthly	100.00	
	Golden River	Lighting Strikes	Annually	200-3000	
	Traffic Counter 1038	6 Volt Lead Gel.			
	Streeter AMET	Rechargeable Batteries	21 Days	11.00	
	Traffic Counter 160	6 Volt Lead Gel	21 Days	11.00	
	Streeter AMET	Rechargeable Batteries			
Arkansas	Portable Counters	Batteries	2 Months	5.00	
	Fixed Counters	Electronic Components		5.00-100	
	Portable Scales	Minimum			
Delaware	Portable Counters	Timer & Battery		20.00	
	Fixed Counters	Timer			
	Weigh-In-Motion	Computers	Infrequent		
	Portable Scales	Load Cells & Readout	2 Months	950.00	
Hawaii	Traffic Counters	Drive Motor	5-10 Years	200.00	
	Portable Scales	Lead-In Wires	Annually	200.00	
Idaho	Portable Counter	Power Supply & CPU Board	2 Years	125.00	
	Fixed Counter-TELAC	CBS Coupler & Memory Ram Chips			
	Weigh-In-Motion				
	Permanent Weigh Station				
	Fixed Counter-Streeter	Relays			
Illinois	Portable Counter-Classifier				
	Fixed Counters				
	Portable Scales	Load Cell	60-120 Days	500.00	Wiring Cables
	Permanent Weigh Station	Load Cell	2 Months	1000.00	
Iowa	Portable Counters	Batteries, Fuses, Clocks			
	Fixed Counters	Lightning, Power Failures			
	Portable Scales	Jamming	Annually	140.00	
Kansas	Portable Counters 160 JR	Counter Unit	Annually	15.00	
	Portable Counters MR101/B	Printer, Clock		30.00/Yr.	
	Fixed Counters	Fuses, Components		5.00	
	Portable Scales	Handle, Diaphragm	5 Yrs.	220.00	
Louisiana	Weigh-In-Motion	Load Cell Transducers	Annually	11000.00	
		Roadway Frames	3 Yrs.	3500.00	
Missouri	Portable Counters	Battery	3-6 Months	8.00	
	Fixed Counters	Routine			
	Portable Scales				
	Permanent Weigh Station				
Nebraska	Portable Counters			7000.00/Yr.	
	Fixed Counters			7000.00/Yr.	
	Permanent Weigh Station			21000.00/Yr.	
North Carolina	Portable Scale	Load Cell	5 Yrs.	40.00	
	Permanent Weigh Station	Load Cell Power Supply Plus Other Electrical & Mechanical	Annually	500.00	
Ohio	Portable Counters			10.00	
	Fixed Counters				
	Weigh-In-Motion				
	Portable Scales				

APPENDIX H

MANUFACTURERS AND SUPPLIERS OF PAVEMENT CONDITION EQUIPMENT

Manufacturer or Supplier and Location	Equipment Type: Structural Capacity	Surface Distress	Friction	Roughness	Traffic Counters	Portable Scales	WIM
Ametron					●		
Bison Instruments Minneapolis, Minnesota			●				
Bradbar, Inc. Little Rock, Arkansas			●				
Bridge Weighing Systems, Inc. Warrensville Heights, Ohio							●
Burr-Brown Tucson, Arizona		●					
Cline Tractor Co. Arcadia, Florida				●			
CMI-Dynamics Hampton, New Hampshire					●		●
Donohue and Associates Waukesha, Wisconsin	●						
Dynatest Consulting, Inc. Ojai, California	●	●		●			
Earth Technology Corporation Long Beach, California		●					
Eldec Corporation Lynwood, Washington						●	
Electro General Corp. Minnetonka, Minnesota		●					
Fisher-Porter					●		
Flight Research Richmond, Virginia		●					
FMC Massilon, Ohio			●				
Foundation Mechanics, Inc. El Segundo, California	●						
General Electrodynamics Arlington, Texas						●	
Golden River Corp. Rockville, Maryland					●	●	●
GR Electronics, Ltd. Santa Monica, California		●					
Gulf Applied Radar Houston, Texas	●						
Harding-Lawson Associates Novato, California	●						
Hewlett-Packard Corvallis, Oregon		●					
Highway Products International, Inc. Paris, Ontario		●	●	●			
Hogentogler	●						
Instrumentation Marketing, Inc. Burbank, California		●					
International Cybernetics Corp. Largo, Florida		●					
James Cox & Sons, Inc. Colfax, California	●		●	●			
K. J. Law Engineers Farmington Hills, Michigan		●	●	●			
KLD Associates, Inc. Huntington Station, New York		●					
KUAB (Pave Tech) Redmond, Washington	●						
Leupold & Stevens Beaverton, Oregon					●		
Load O Meter Co. Baltimore, Maryland						●	
MAP, S.A. Basel, Switzerland	●						

Manufacturer or Supplier and Location	Structural Capacity	Surface Distress	Friction	Roughness	Traffic Counters	Portable Scales	WIM
	Equipment Type						
Norand Corp. Cedar Rapids, Iowa		●					
Novak, Dempsey & Assoc., Inc. Palatine, Illinois		●		●			
Nu Data Corp. Little Silver, New Jersey		●					
PASCO Corporation Tokyo, Japan		●					
Pavement Consultancy Services, Inc. (Phoenix) Arlington, Virginia	●						
Radian Corp. Austin, Texas							●
Rainhart Co. Austin, Texas				●			
Redland Automation					●		
Safetran Traffic Systems Colorado Springs, Colorado					●		
Sarasota Automation, Inc. Sarasota, Florida					●		
Security Records Systems Lacey, Washington		●					
Senstek, Ltd. Saskatoon, Saskatchewan						●	
SIE-Geosource Fort Worth, Texas	●	●					
Siemens-Allis/PAT Atlanta, Georgia							●
Sites Traffic Data Systems Equipment Colorado Springs, Colorado					●		
Soiltest, Inc. Chicago, Illinois	●		●	●			
Streeter Richardson Grayslake, Illinois					●	●	●
Techwest Enterprises, Ltd. Vancouver, British Columbia		●		●			
Telac					●		
Temiflex Corp. Willow Grove, Pennsylvania		●					
TESSCO, inc. Reno, Nevada		●					
Traffic Data Systems, Inc.					●		
Traficomp					●		
Vanguard Instrument Corp. Melville, New York		●					
Veeder Root Hartford, Connecticut					●		

Information in this table represents the best information available at the time the report was written. It is possible that other suppliers may exist; any omission from this list was inadvertent.

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