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**Federal Highway
Administration**

Demonstration Projects
Program

PAVEMENT PROFILE MEASUREMENT SEMINAR PROCEEDINGS

FT. COLLINS, COLO.
OCTOBER 5-8, 1987

VOLUME II DATA COLLECTION EQUIPMENT

Demonstration Project No. 72

Automated Pavement Data Collection Equipment

FHWA-DP-88-072-004

April 1988

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16. Abstract
The objective of this seminar was to demonstrate the state of the art in data collection equipment used in measuring pavement roughness and profile. In a workshop environment, information was provided for managers and technicians to meet the following specific objectives: (1) To present the theory of operation of pavement monitoring equipment, and (2) Provide an overview of use and application of data in conjunction with planning, pavement management, and design.

The report documenting the program is prepared in three volumes. Volume I, Seminar Overview, presents a general overview of the seminar. Volume II, Data Collection Equipment, provides detailed descriptions of the equipment demonstrated and data collected. Volume III, Workshop Summaries, contains a report on the workshop findings. Each volume is published separately.

Included in this volume is a summary of all equipment including photographs and typical data output from all the devices. In addition, a complete equipment description, as provided by the equipment demonstrators, completes this report.

Implementation
Results from this demonstration provided information to highway agencies in selecting and operating automated data collection equipment or programs in a cost-effective manner. Using information collected during the seminar, a cross reference of pavement profile equipment data is available. This provides a datum for reported information in such publications as HPMS, legislative requests, pavement condition studies, and others.

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PAVEMENT PROFILE MEASUREMENT SEMINAR

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VOLUME II

I. INTRODUCTION

During the week of October 5 - 8, 1987 nearly 200 engineers and technicians met in Fort Collins, Colorado to participate in a seminar on pavement smoothness measurement. The program included presentations by recognized authorities on the subject, a demonstration of smoothness measuring devices, field data collection using the equipment demonstrated, and a series of workshops on the subject. The participants were comprised of researchers, data collectors, users and sales representatives of the public and private sector from across the United States and Canada. A three-volume report was developed to address the three main topics of the seminar: Seminar Overview (Volume I), Data Collection with Various Roughness-Measuring Devices (Volume II), and Workshops (Volume III).

This report (Volume II) is intended to disseminate the information on state-of-the-art pavement smoothness measuring devices. It is intended to assist agencies in the selection of new equipment that is suitable to their specific needs in terms of cost and data collection capabilities.

One of the goals of the pavement smoothness seminar was to bring together as many pavement smoothness measuring devices as possible, and give the seminar participants an opportunity to familiarize themselves with what is available in the field of pavement smoothenss evaluation. In addition they could see for themselves the advantages or shortcomings of a particular device.

A total of twenty devices participated in the pavement profile measuring seminar. The devices ranged from the relatively simple slow moving profilographs capable of charting a longitudinal profile to high-speed noncontact measuring equipment. The most widely represented system was the latter type. The following devices participated in the seminar:

1. Calibration and Construction Control Systems
   Profilograph (Rainhart)
   Profilograph (McCracken)
   E.W. Face Dipstick
   Ames, Profilograph

2. <u>Response Type Systems</u>

Mays Ridemeter (Car & Trailer based)
Cox Roadmeter
B&K Accelerometer

3. <u>Accelerometer Based Systems</u>

Portable Universal Roughness Device or PURD
Dynatest 5000 Roughness Distress Meter
Self-Calibrating Roughness Unit
Automatic Road Analyzer or ARAN

4. <u>Non-contact Profile Measuring Systems</u>

K.J.Law M8300 Roughness Surveyor
Laser Road Surface Tester
K.J.Law 690 Digital Non-contact Profilometer
Pro Rut System
South Dakota Profilometer
Surface Dynamics Profilometer
PURD (w/multiple accelerometers option)
ARAN (w/multiple accelerometers option)

A list of equipment operators is located in Appendix A. The list contains all participating devices, equipment owners, and operators' names and addresses. This list should facilitate any inquiry regarding a specific device in case the detailed equipment report in Appendix B does not sufficiently address all questions regarding a specific device.

The information contained in Appendix B was provided by the equipment owners/operators in accordance with a questionnaire that was given to the participants prior to the seminar. The purpose of this questionnaire, which can be found in Appendix D, was to obtain specific information about the various devices. The responses to the questionnaire varied from very brief equipment descriptions by the operators, to extensive documentation by manufacturers as well as some state transportation agencies.

Appendix C contains the roughness equipment correlation guidelines. These guidelines were distributed during the equipment operators' orientation session. The main purpose of that meeting was to ensure consistency in the data collection phase of the seminar.

II. EQUIPMENT DETAIL SUMMARY

Because of the rather voluminous nature of the detailed equipment description that was furnished by the various equipment operators, a summary section was prepared for each profile-measuring device. This summary typically contains one or two photographs of the device, a short paragraph describing principal components and the type of roughness index generated by the device. Many of the devices were capable of generating additional information that was not demonstrated during the seminar. However, these additional capabilities are described in the detailed equipment reports in Appendix B.

The following pages provide a brief description and photographs of the equipment used at the seminar by the various participants.

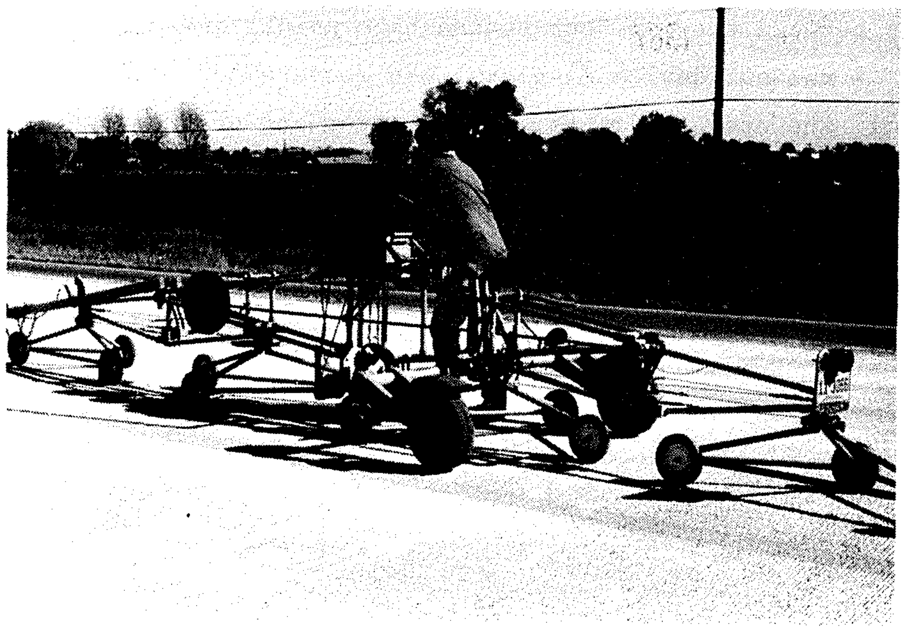
Colorado Devices

The McCracken and Rainhart profilographs are manually operated longitudinal profile measuring devices. The main difference between the two systems is that the Rainhart profilograph employs an intermediate truss and support wheels in defining the averaging reference plane from which the pavement deviation is measured. The McCracken reference plane is defined by the two clusters of support wheel at the ends of the simple truss.

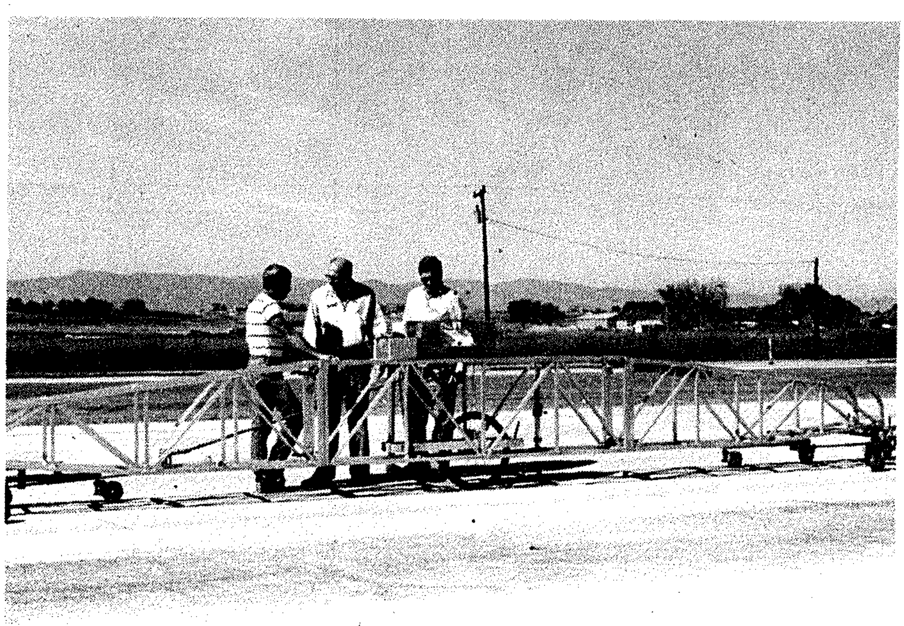
Both profilographs use strip chart recorders to identify pavement roughness. In the data reduction, a 2/10 inch (0.2") blanking band was used to filter out texture-caused roughness.

The McCracken profilograph truss can be disassembled into three sections for transporting the equipment. It is currently used in Colorado's smoothness specifications for concrete pavement projects.

Colorado Department of Highways



Rainhart Profilograph

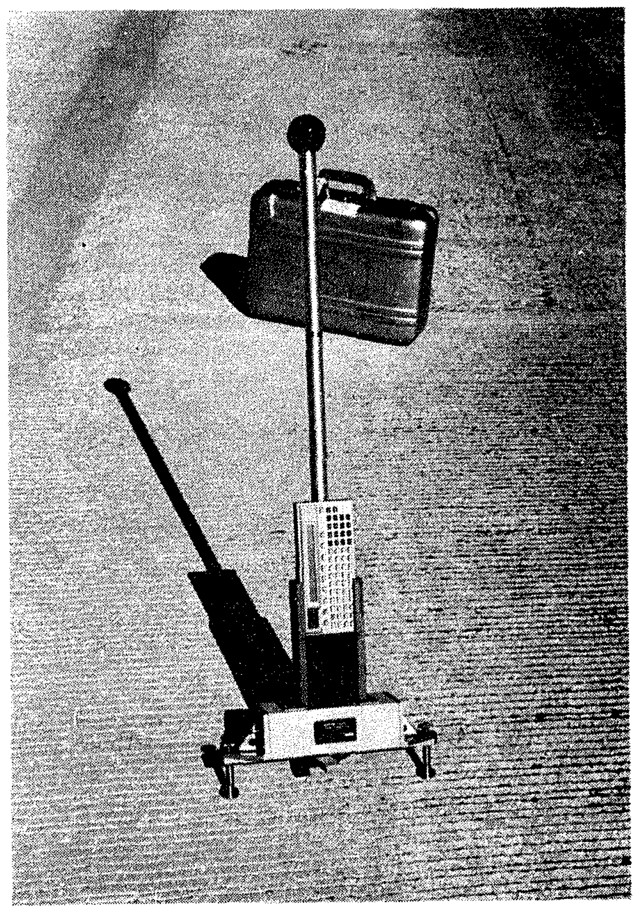


McCracken Profilograph

E. W. Face Company

The Dipstick represents a precision auto-recording rod and level replacement system primarily intended for calibration purposes. Elevation differences between the one-foot spaced base points are measured by a slope indicator. A readout device displays this measurement, and in the case of the manual model, the operator makes a voice-recording of the readout for later data processing.

The automated dipstick (with 18 K micro computer/printer) permits in-the-field calculation of profile statistics with output of IRI, FF-number, elevation, curvature values as well as a plot of the measured surface.



Dipstick
The computer attached stores and analyzes the data.

AMES PROFILOGRAPH

Central Direct Federal Division

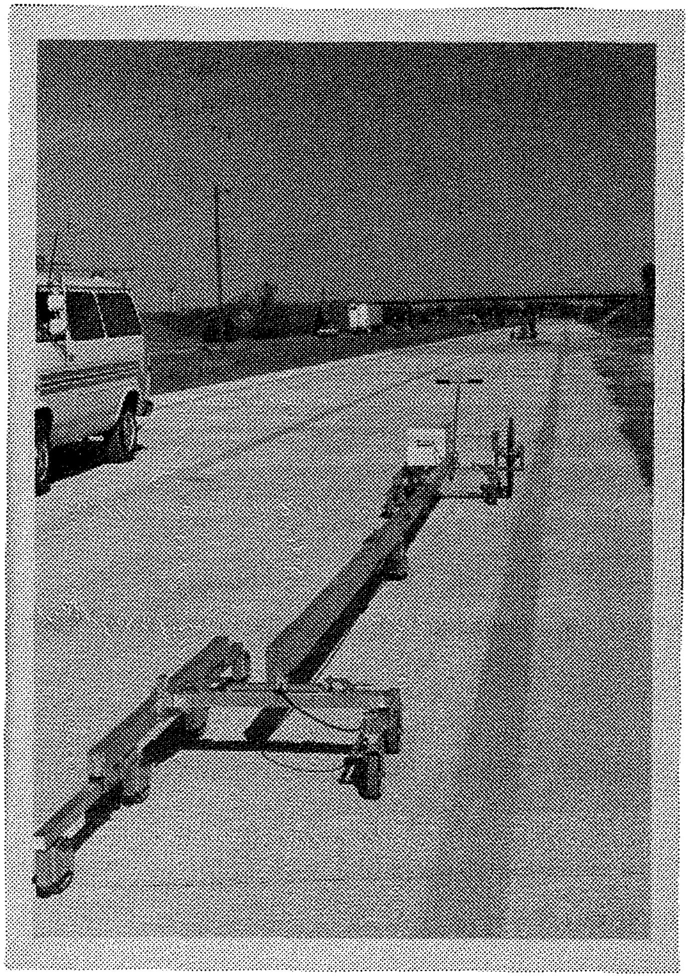
The information for the Ames profilograph presented here constitutes an excerpt from a report by Allan S. Miller and Candace E. Watson entitled, "Pavement Rideability Study."

The report focuses on a correlation between the rolling straight-edge and a California-type profilograph.

This excerpt from the above report deals with operating experiences of the Ames profilograph, as well as a list of California-type profilographs, schematic sketches, and samples of comparison roughness traces for the McCracken and Ames profilographs.

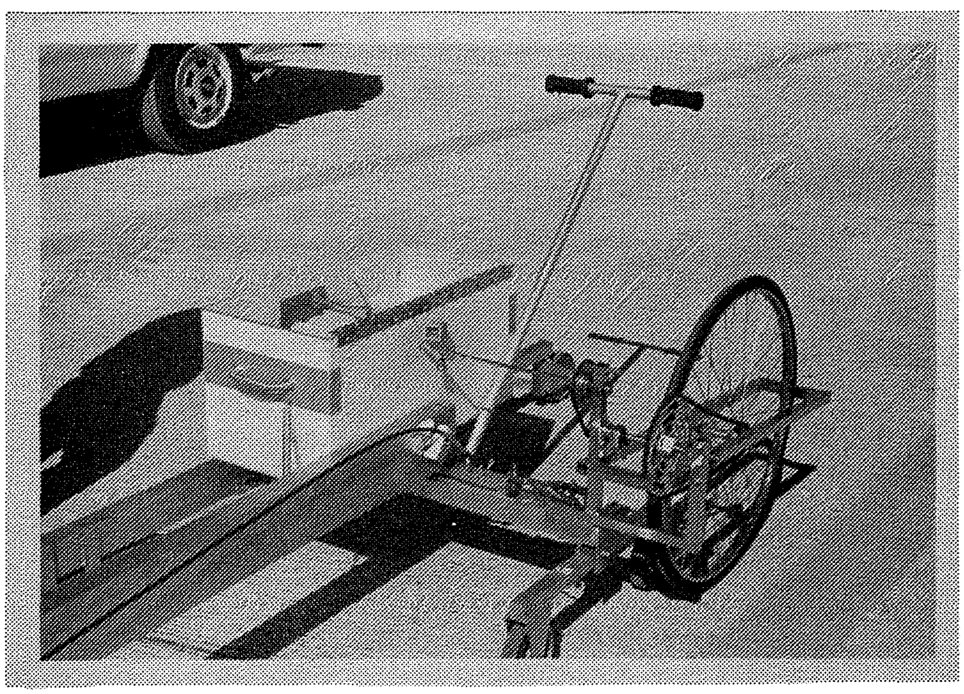
Reference: "Pavement Rideability Study"; Central Direct Technical Division, 1987; Allan S. Miller; Candace E. Watson

Central Direct Federal Division of FHWA



The Ames Profilograph is a low-cost smoothness testing device. Simple and light-weight construction are some of the positive aspects of this equipment. The manually propelled device produces a profile chart that is analyzed using the California chart method. The device is easily assembled and disassembled by one person to facilitate transportation of the equipment.

The two photographs show an overall view of the equipment and a close-up view of the recording mechanism.



No smoothness data was collected with this device; it was available during the open house and during the demonstration session.

Wyoming

The Mays Ride Meter used by the Wyoming Highway Department is mounted in a 1986 Chevrolet Caprice consisting of the following equipment:

Odometer

Rotary Transmitter to convert axle-body movement to an electrical signal.

Pavement Condition Recorder to record the movements and accumulate the total roughness.

Data Playback Unit to transfer the casette-based data to an IBM-XT computer

Data output consists of measured "counts" based on the relative axle-body motion and is translated to the Rainhart strip chart recorder as follows:

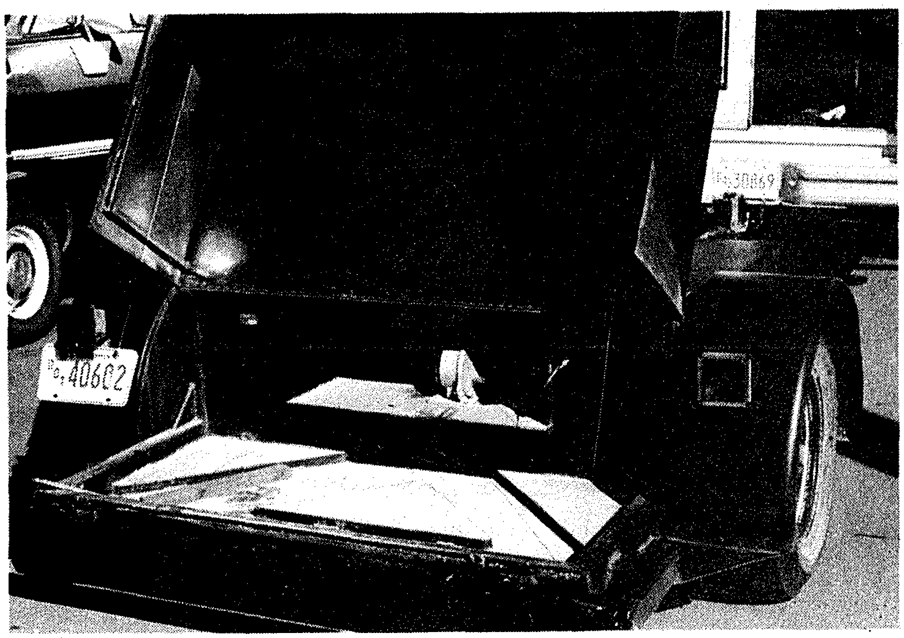
Inches Chart Roughness/Miles = Total Count/(Net length * 64).

Sixty-four counts of the Mays meter is equal to one inch of roughness as measured by the Rainhart strip chart recorder.

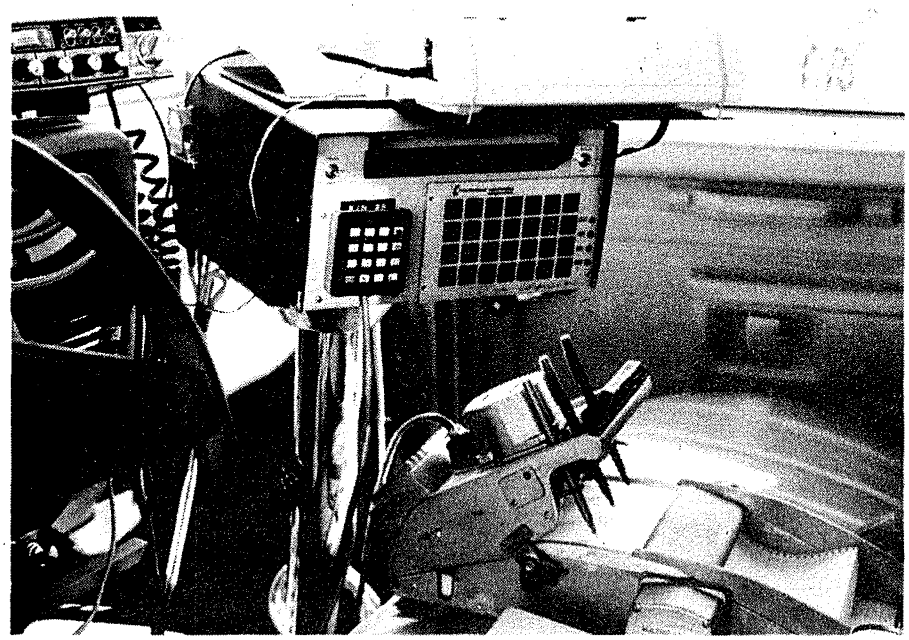
Mays Ridemeter

Western Direct Federal Division of FHWA

The trailer mounted roughness measuring devices that were demonstrated by this agency are a dual system consisting of the Mays Ride Meter and a B & K Model 2231 integrating meter (accelerometer). The additional accelerometer was intended to serve as a check for inconsistencies experienced with the Mays Ride Meter (MRM). Although the B & K accelerometer output is not directly equivalent to the MRM numbers, they are of a similar scale and could be correlated via the Root Mean Square (RMS) acceleration.



Mays Ridemeter (Trailer and B & K Accelerometer)

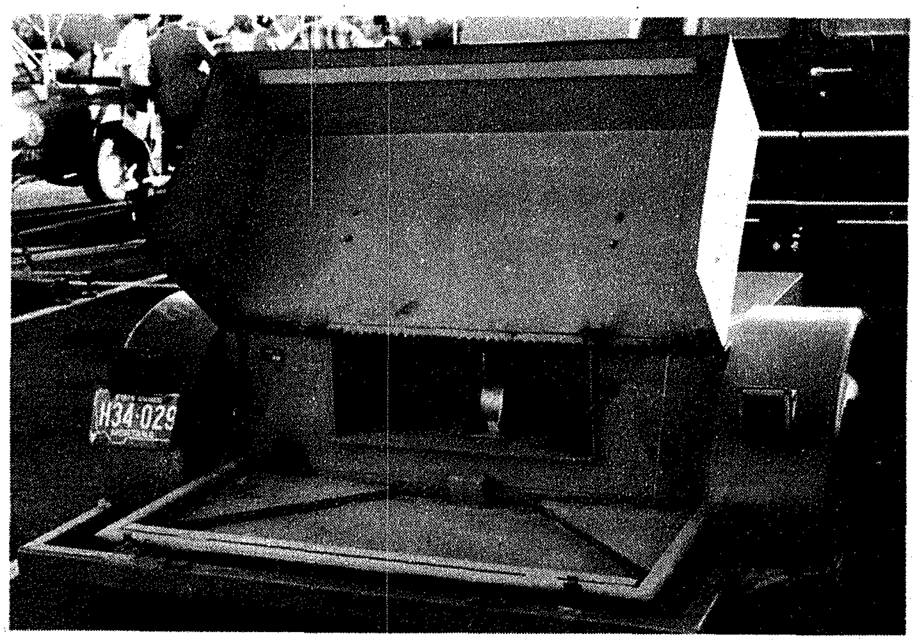


Computer and Recorder for Mays Ridemeter and B & K Accelerometer
Western Direct Federal Division, FHWA

Montana

Montana's trailer mounted Mays Ride Meter is a Rainhart 890T trailer as developed by the Texas State Department of Highways and Public Transportation. The instrument continually logs the pavement surface by recording magnitude, direction, and summation of trailer axle to body excursions, together with synchronized distance measurements and landmarks.

The addition of a pavement condition recorder (PCR2000) and a Zenith Z-171 portable computer facilitate data collection and storage. Data output consists of route, direction and lane information in addition to Mays count and Mays distance information by 1/10 of a mile intervals.

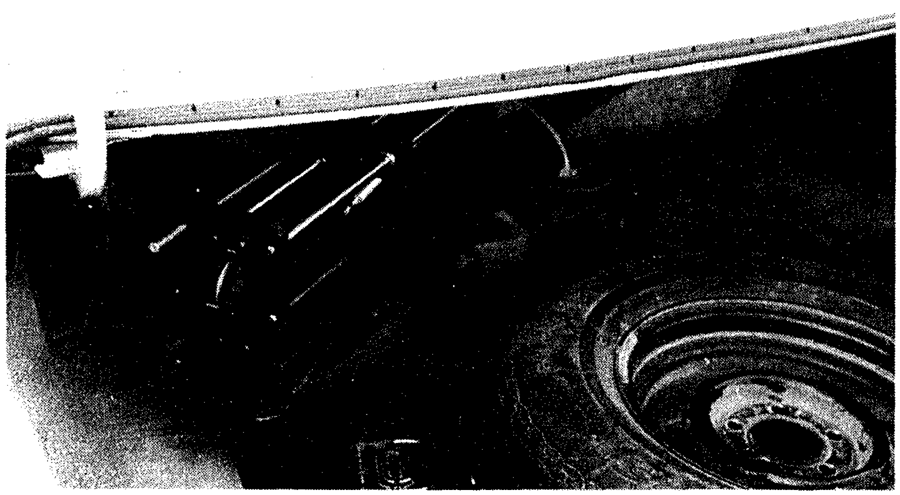


Mays Ridemeter
Montana Department of Highways

Nevada

Nevada's Cox roadmeter is a programmable response-type device that records deviations in the vehicle body movements as it relates to the axle. Deviation from the null are registered and accumulated over the section length. Peak values are recorded in 1/8 inch increments. This data, fed into a data acquisition system, outputs accumulated count number which in turn is converted to vehicle displacement counts and, ultimately, inches per mile.

Cox Roadmeter



Sensor for Cox Roadmeter

Ontario, Canada

Ontario's portable universal roughness device (PURD) measures roughness using a trailer axle mounted accelerometer. The equipment demonstrated at the seminar also had an optional multiple accelerometer system for generation of IRI data. A microcomputer based pavement condition rating keyboard permits recording of pavement distress types, severity and extent measurements. Also included is a distance measuring instrument (DMI) to accurately measure all surveyed sections and record locations of inventoried items.

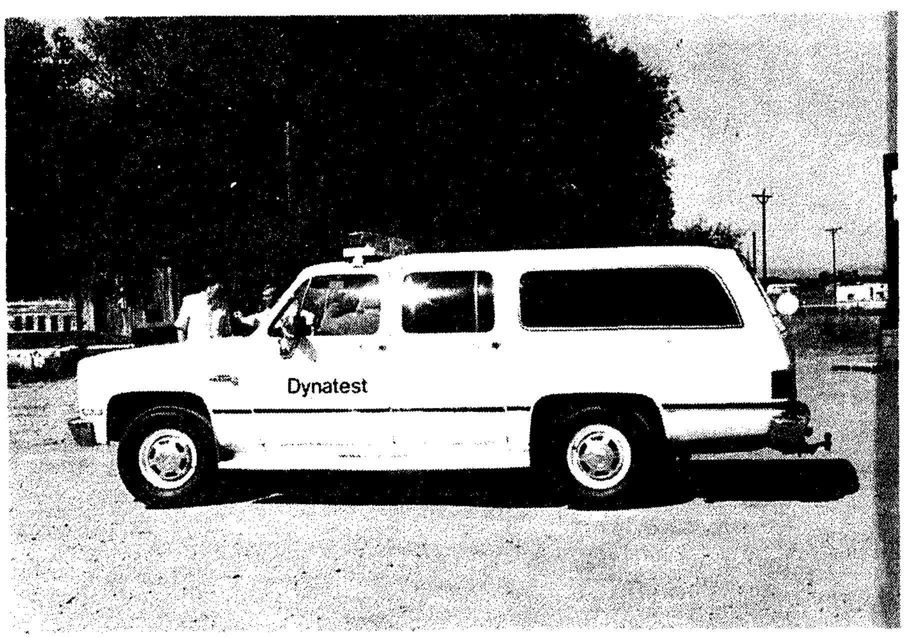
The main difference between the equipment description in the report and the equipment demonstrated, is that a trailer-based system was used instead of the van-based system described in the equipment description.

Portable Universal Roughness Device (PURD)

Mississippi

Mississippi arranged for the furnishing of a Dynatest 5000 road roughness measuring system. The response type (RTRRMS) uses an ultra precision accelerometer to generate the statistic root-mean square vertical acceleration. The van-mounted system consists of the following components:

1. Digital distance encoder
2. Processor and microcomputer for plotting, printing and data storage
3. A chassis-mounted accelerator
4. Hand-held event and start/stop keypads
5. Dual beam calibration assembly
6. Software to accomplish various data processing tasks



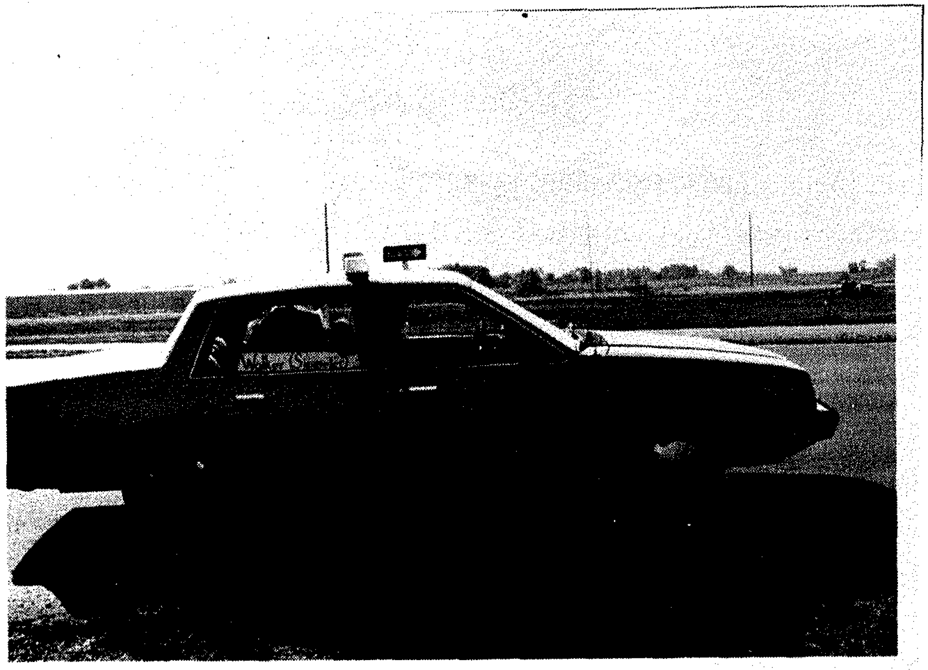
Dynatest RDM

Texas

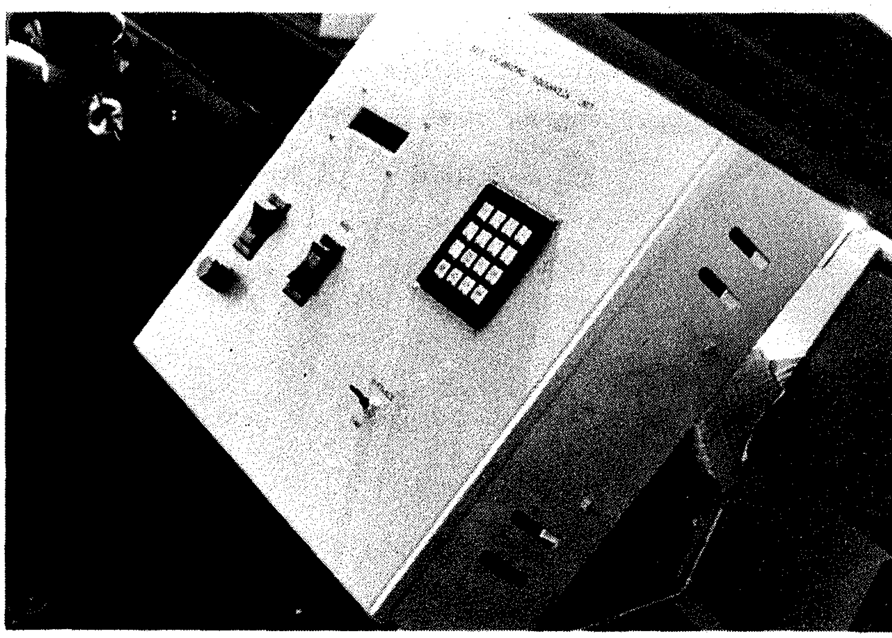
The Walker Roughness Device demonstrated by the Texas State Department of Highways is also known as the self-calibrating roughness unit (SIometer). The car-based system consists of a trunk-mounted accelerometer as the primary sensor unit, a main control module and, optionally, a computer for data storage. The accelerometer measures the vertical acceleration of the vehicle and the signal is transmitted to the main control unit for digitizing and processing.

The portable unit is easily installed in any vehicle because of the self-calibrating feature.

Prior to actual measurements the vehicle's response is statisically modeled over a short road section. The model parameters are later used in the measuring process to remove the vehicle's characteristics.



Texas Self-Calibrating Roughness Unit



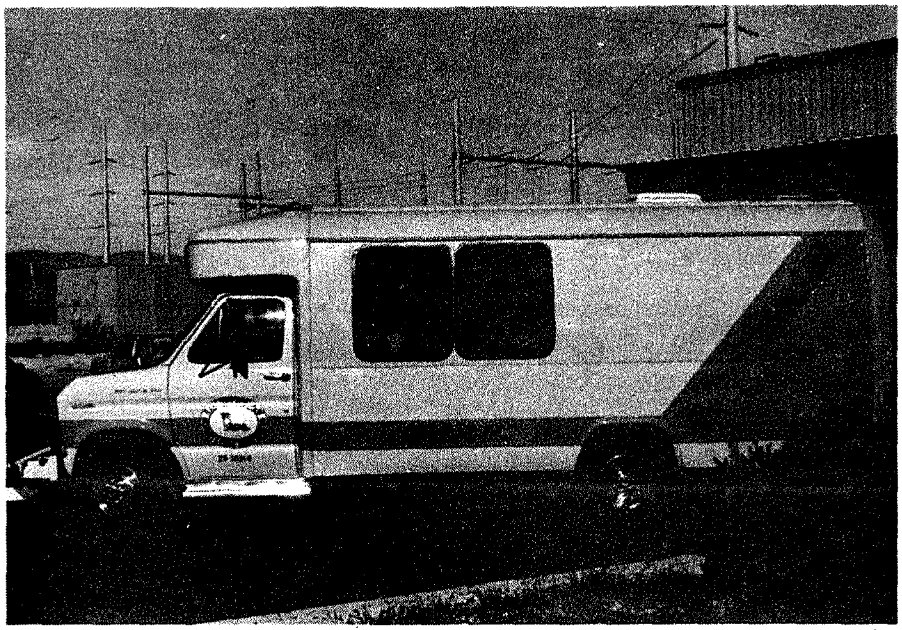
Control Console for the Texas Self-Calibrating Roughness Unit

Texas

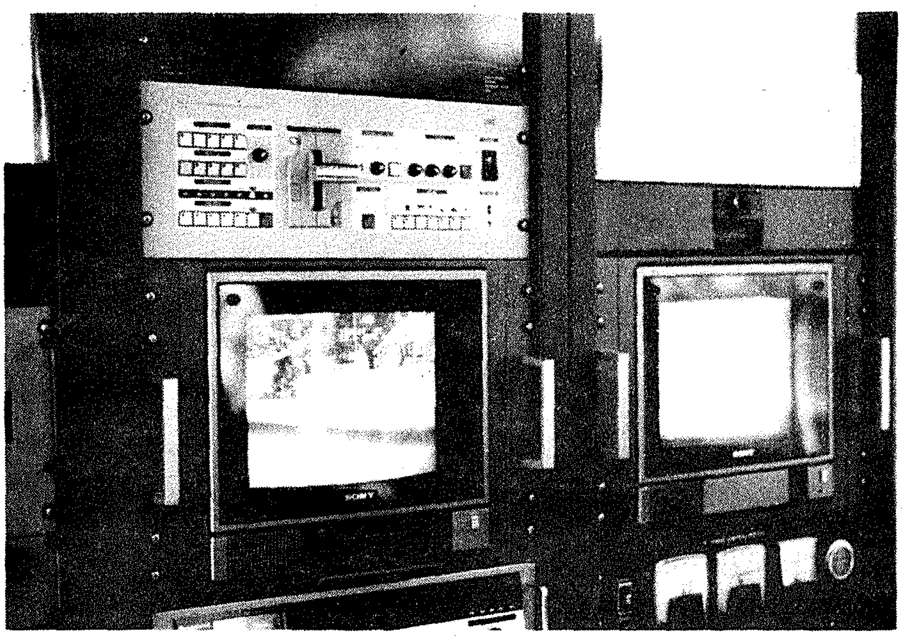
The second roughness measuring device provided by the Texas State Highway Department was the automatic road analyzer (ARAN III).

This non-contact, accelerometer-based roughness measuring system is used to report overall condition of the state maintained highway network. In addition to roughness measuring capabilities, this system also performs pavement distress surveys using a dual video camera setup, and sonar sensors for rut depth measurements. Travel speeds up to 50 miles per hour are feasible for measuring distress and roughness. However, the body mounted accelerator and an axle mounted accelerator evaluate pavement roughness at speed of 30 to 50 mph. The measured vertical accelerations are averaged for both wheel tracks.

On-board display of roughness in units of root mean square of vertical accelerations (RMSVA) and mean rectified slope (MRS) is on a 9-inch CRT. Raw data is stored for post-processing of longitudinal profile and roughness statistics such as the international roughness index (IRI). The system is equally sensitive to all wavelengths from 1 foot to 300 feet independent of the body-to-axle movement.



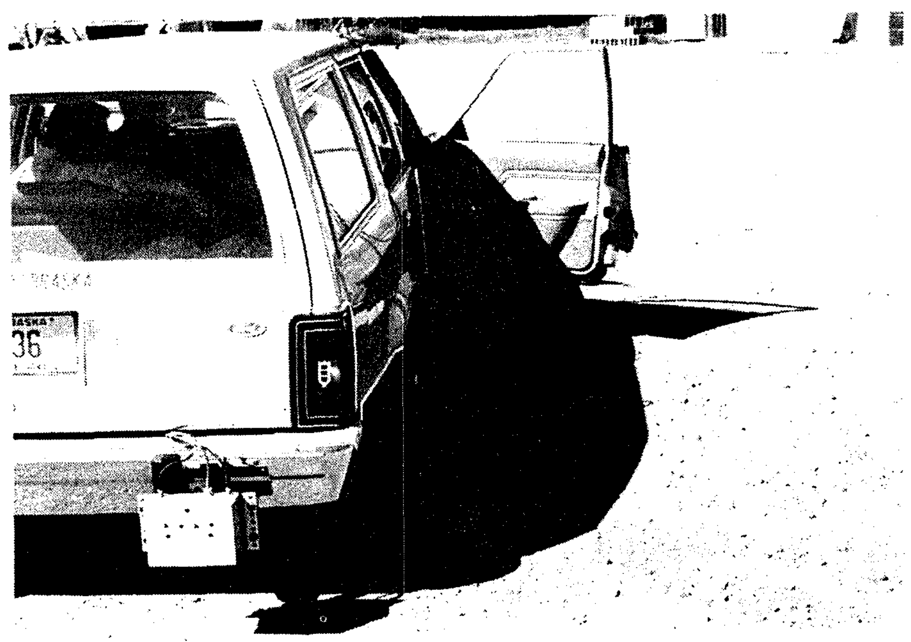
ARAN III



Interior view of the ARAN III

Nebraska

The K.J. Law M8300 roughness surveyor is a ultrasonic non-contact profile measuring system. The car-based unit consists of a bumper mounted canister containing the accoustic probe and receiver, and an accelerator. The accoustic probe measures displacement only. The microprocessor computers can be programmed to provide Mays, PCA, RMS or other vehicle response statistics. The Mays statisics was selected for this project and the output units are in inches per mile.

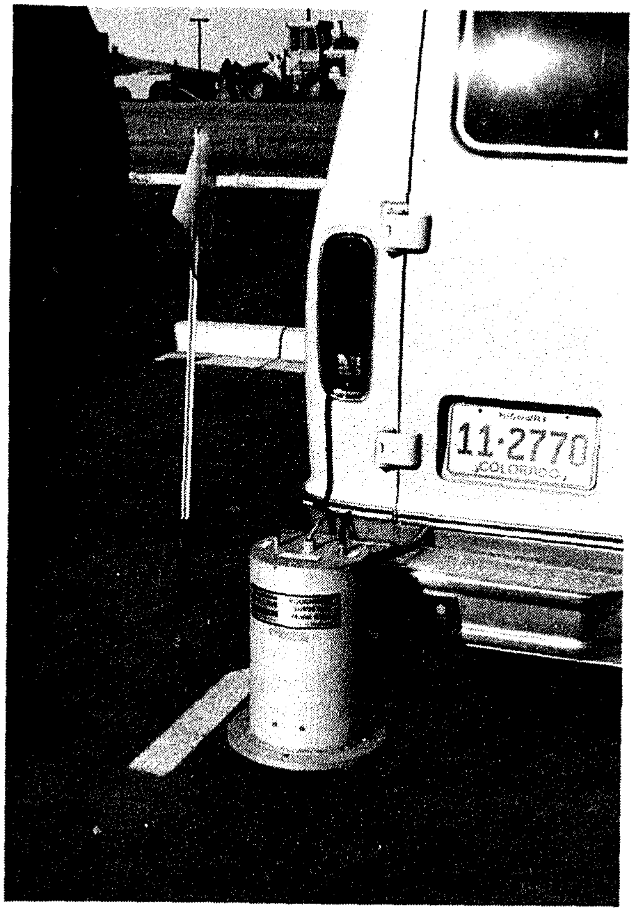


K.J. Law M8300

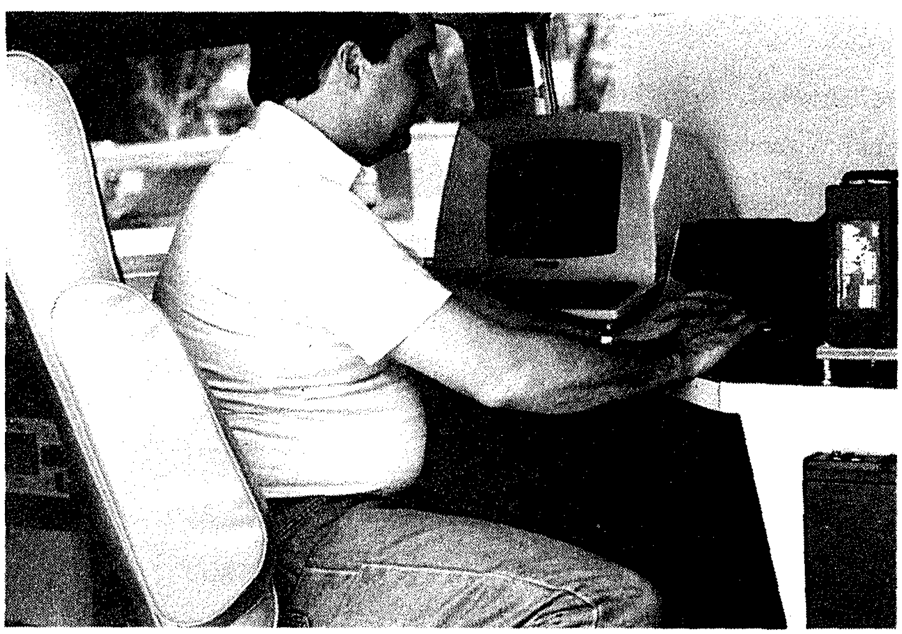
Nebraska Department of Roads

Colorado

Colorado's K.J. Law M8300 roughness surveyor is an ultrasonic non-contact profile measuring system housed in a van. The canister containing the acoustic probe, receiver, and accelerometer is mounted on the left side of the rear bumper. The acoustic probe measures displacement only. Since Colorado's K.J. Law is used for roadway inventory, a video camera has been installed in addition to an automated rutting measuring device. A printer is used for producing a on-board hard copy of the data. All data is stored on magnetic tape for later transfer to PC's and subsequent editing and analysis. Roughness units are programmable but the Mays statistic is used and the output is in inches per mile.



Canister containing sensors for Colorado's K.J. Law M8300



Interior view of K.J. Law M8300

Illinois

Infrastructure Management Services (IMS) demonstrated the use of lasers in the measurement of pavement roughness. Eleven lasers mounted on a front-bumper mounted beam are used in various configurations to measure the following:

Rut depth - all lasers are used
Longitudinal profile - lasers 2 or 8 (to measure wheel track profiles)
Macrotexture - Lasers 2 and 8
Cracking - Lasers 2, 4, 6 and 8

The lasers are numbered 0 through 10 from left to right as seen in the direction of travel and their setup is from "regular" lasers to "angled" lasers and "combination" lasers to permit the variety of measurement techniques.

Longitudinal profile is measured simultaneously by recording and analyzing the following:

a. Vertical movement of laser as measured with the accelerometer.
b. Vertical movement of the pavement and laser, as measured with the laser.
c. Horizontal velocity of the laser, as measured with a pulse transducer.

From the above input a true profile slope is computed. IRI (Quarter car) and RMSVA (MO) are calculated from the true profile slope for each 20 meter section.

Laser RST IMS-Illinois

Interior view of Laser RST

AASHTO MATERIALS REFERENCE
LABORATORY PROGRAM
(FHWA)

The K.J. Law 690 DNC Surface Dynamics Profilometer is an inertial system that records road profiles at normal vehicle speeds.

The van-based system consists of the following:

1. Non-contact pavement sensors
2. Accelerometers
3. Digital distance encoder
4. Profile computers
5. Software (Operating system, profilometer program)
6. CRT terminal and printer
7. Magnetic tape recorder
8. Optional software

Among the pavement rougness simulation programs the following is available:

BPR Roughometer
Mays Ride Meter - Vehicle and trailer
PCA Ride Meter
Cox Ride Meter
Root Mean Square Acceleration (RMSA)
Present Servicability Index (PSI)

The unit has numerous other capabilities in the pavement performance evaluation area. They are listed in the equipment section of the report.

K.J. Law 690 DNC Profilometer

UMTR1/Michigan

The PRORUT System as demonstrated by UMTRI was designed to perform as a fully integrated pavement condition survey system as well as a relatively accurate and inexpensive profiling system. The use of laser sensors in the original design was changed to infrared transducers on the unit used in the demostration. Profiling and rut-depth measurements are easily combined with this sensor arrrangement. The on-board computer controls the system operation, including calibration and data processing. Two accelerometers situated above the wheel tracks allow roughness computation for the separate wheel paths with IRI values as well as profile plot output.

Pro Rut System (FHWA)

South Dakota DOT

South Dakota's profilometer system consists of a linear accelerometer and a non-contact ultrasonic ranging device. In addition to the pavement profile capabilities, the ultrasonic sensors are used for rut depth measurements. A microcomputer controls the devices that measure the vehicle's horizontal distance, vertical position, and height above the pavement are housed in a van. A printer for hard copies and disk driven for data storage comprise the data storage system.

The software is capable of producing a number of statistics, specifically in addition to the profile plots the following is available:

Mays Index
PCA Index
PSI
RMS Acceleration Sprung Mass
Average Rut Depth

The profile plots are produced for one wheel path only. The above statistics are used to represent combined wheel paths.

Road Profiler

Interior view of Road Profiler

Nebraska

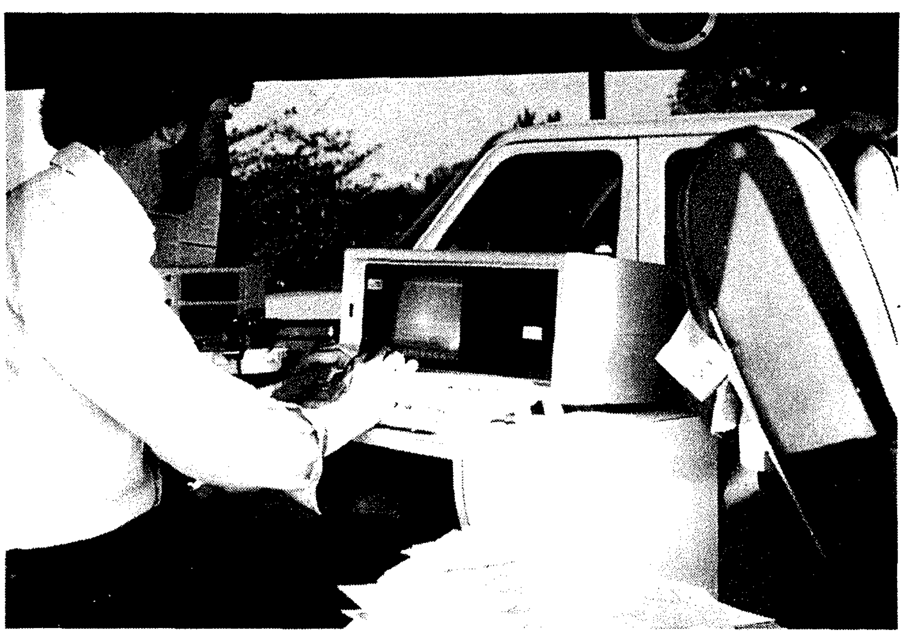
Nebraska's profilometer was developed using the South Dakota profilometer design. The description of the South Dakota equipment is applicable for Nebraska's profilometer. As is the case with the South Dakota system, automated rut-depth measuring facility exists on Nebraska's profilometer.

SD Profilometer Nebraska Department of Roads

Texas

The Texas Surface Dynamics Profilometer (SDP) measures longitudinal pavement profile in each wheel path. A non-contact laser probe and an accelerometer located over each wheelpath are used to measure the pavement profile and the information is processed by a 80286 CPU based computer. Software permits sampling rates at ten or twenty samples per foot, either filtered or unfiltered. Only longitudinal profile is being measured by this equipment. Roughness values are computed and reported in units of Servicability Index (SI) for each wheel path. The program is also capable of simulating a Mays Ride Meter count.

Texas Surface Dynamics Profilometer



Interior view of Texas Surface Dynamics Profilometer

III. TYPICAL DATA OUTPUT

This section contains typical data output from the various smoothness measuring devices.

Some of the equipment not only had capabilities to produce the basic roughness statistics expressed in inches per mile roughness, but also reported additional simulated roughness statistics, such as the international roughness index, PCA counts and Root Mean Square (RMS) acceleration. Most of the sample output summaries also include information on test location, date, time, distance, and other housekeeping information.

The sample strip charts for the Rainhart and McCracken profilographs represent only a short section (approximately 150 feet) of the respective test section and subsection. However, the tables list the roughness values for all subsections. These values were obtained using the California chart reduction method which uses a 0.2 inch filter to exclude roughness values that are less than 0.2 inches.

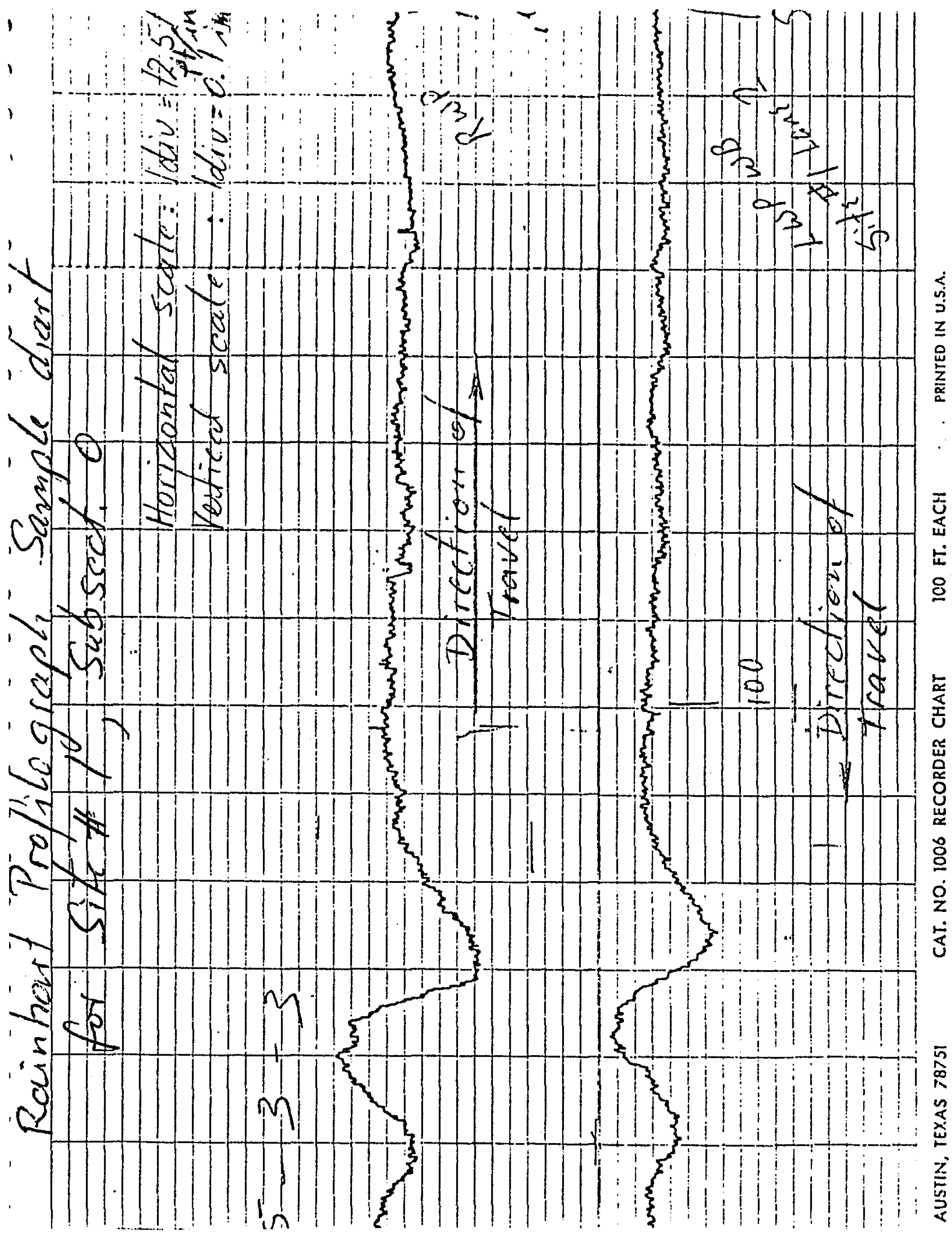
Most of the devices generated a tabular output of roughness values. Some of the equipment had capabilities to produce profile charts by post-processing the data subsequent to the test runs.

RAINHART PROFILOGRAPH
COLORADO DEPARTMENT OF HIGHWAYS

Site 3, Run 1

LWP (in/mi)	RWP	Sub-section
5.5	4.5	0
7	9.5	01
9.5	4	02
4	1	03
3.5	1.5	04
11	2.5	05
10	13	06

Data in table is summarized from strip chart

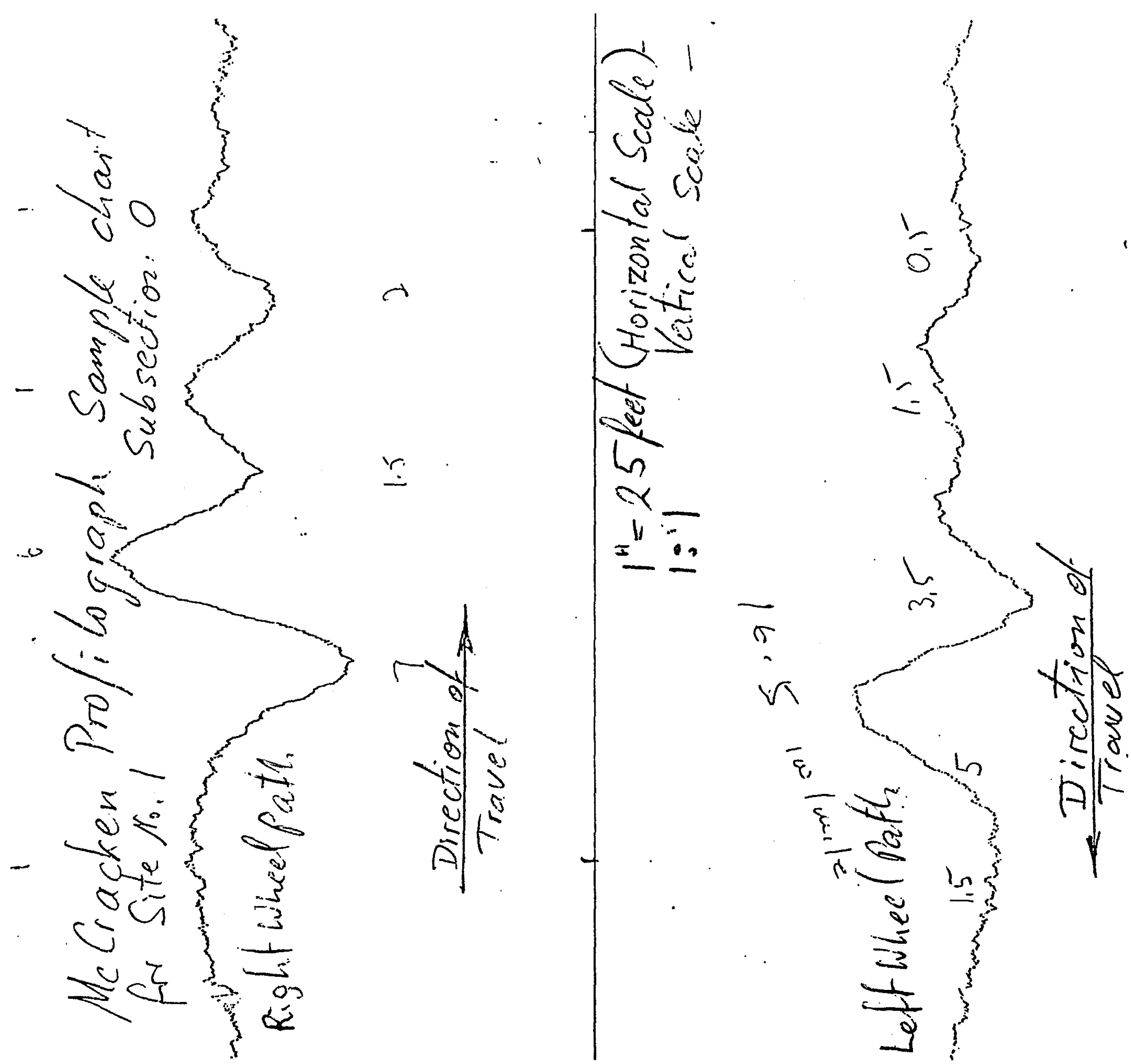


McCRACKEN PROFILOGRAPH
COLORADO DEPARTMENT OF HIGHWAYS

Site 3, Run 1

LWP (in/mi)	RWP	Sub-section
21	16	0
42	16	01
23	15.5	02
19.5	18	03
21	8.5	04
42.5	19.5	05
40	32	06

Data in table has been summarized from strip chart.



DIPSTICK
E. W. FACE COMPANY

Raw data has been analyzed using the "DIP_IRI" computer program from E.W. Face Co.

Project: SITE_1A Test #: SUB01RWPDate: 09/22/87 Op. bias: NONE

	No. Rdgs	Avg Rdg	Std Dev	Highest Rdg	Hi Pt	Lowest Rdg	Lo Pt
Dipstick Rdgs :	516	0.039	0.0501	0.156	288	-0.085	58
12" Curvatures:	515	-0.000	0.0321	0.089	266	-0.094	58
Pt. Elevations:	517	0.000	8.0455	20.294	516	-2.480	140
Rect. Slopes :	516	1.614	1.3855	7.790	467	0.005	312
IRI Values :	516	1.334	0.1708	2.638	2	1.099	39

Cumulative displacement = 0.833 meters
Composite IRI value = 1.614 millimeters/meter
Composite ACI FF-number = 47.464 (per ASTM E-1155)

MAYS RIDE METER (CAR-BASED)
WYOMING HIGHWAY DEPARTMENT

L21 MAYS RATING

DATE	100587
TIME	1051
INDEX #	103
TEMPERATURE	60
SPEED	30
COMMENTS	4
BEGIN M.P.	0.000
DIRECTION	N
LANE	1
SELECT DCF	01
RECORD MODE	1
OP/VEH/MAYS	111
DIST. INCR.	.100
DCF:1	.16500
CONSTANT:1	1.
COEF.:1	1.

L21 MAYS RATING

DATE	100587
TIME	1050
INDEX #	102
TEMPERATURE	60
SPEED	30
COMMENTS	4
BEGIN M.P.	0.000
DIRECTION	N
LANE	1
SELECT DCF	01
RECORD MODE	1
OP/VEH/MAYS	111
DIST. INCR.	.100
DCF:1	.16500
CONSTANT:1	1.
COEF.:1	1.

EVT	M.P.	NET	CNT
[illegible]	0.000	000000096	
[illegible]	0.100	0.100	76
[illegible]	0.200	0.099	78
[illegible]	0.300	0.099	69
[illegible]	0.400	0.099	61
[illegible]	0.500	0.099	47
[illegible]	0.600	0.099	59
E	0.600	0.000	0

NET LENGTH 0.600
ELAPSE TIME 00078448
TOTAL COUNT 390.

MAYS RIDE METER (TRAILER-BASED)
FHWA, WESTERN DIRECT FEDERAL DIVISION

```
[2] MAYS RATING
DATE               100587
TIME                 1430
AGENCY/STATE          172
ROUTE                   1
SECTION                11
SURF/SPEED             50
BEGIN M.P.           0.00
DIRECTION               N
LANE                    1
SELECT DCF             01
RECORD MODE             1
OP/VEH/MAYS          1928
DIST. INCR.          .100
DCF:1              .16706
CONSTANT:1              0
COEF.:1           .015625

[7]M.P.   NET        CNT
B  0.000  00000064
I  0.100  0.100       95
I  0.200  0.100       79
I  0.300  0.099       58
I  0.400  0.100       62
I  0.500  0.099       63
E  0.599  0.099       86

NET LENGTH          0.599
ELAPSE TIME      00004512
TOTAL COUNT          443.

[5]  SUMMARY
BEGIN M.P.          0.000
END M.P.            0.599
NET LENGTH          0.599
ELAPSE TIME      00004512
TOTAL COUNT          443.
RIDE RATING          11.6

[4]
```

```
[2] MAYS RATING
DATE               100587
TIME                 1430
AGENCY/STATE          172
ROUTE                   1
SECTION                12
SURF/SPEED             50
BEGIN M.P.           0.00
DIRECTION               N
LANE                    1
SELECT DCF             01
RECORD MODE             1
OP/VEH/MAYS          1928
DIST. INCR.          .100
DCF:1              .16706
CONSTANT:1              0
COEF.:1           .015625

[7]M.P.   NET        CNT
B  0.000  00000011
I  0.100  0.100       98
I  0.200  0.100       85
I  0.300  0.099       65
I  0.400  0.099       77
I  0.500  0.099       57
E  0.595  0.095       77

NET LENGTH          0.595
ELAPSE TIME      00004320
TOTAL COUNT          459.

[5]  SUMMARY
BEGIN M.P.          0.000
END M.P.            0.595
NET LENGTH          0.595
ELAPSE TIME      00004320
TOTAL COUNT          459.
RIDE RATING          12.1

[4]
```

```
[2] MAYS RATING
DATE               100587
TIME                 1430
AGENCY/STATE          172
ROUTE                   1
SECTION                13
SURF/SPEED             50
BEGIN M.P.           0.00
DIRECTION               N
LANE                    1
SELECT DCF             01
RECORD MODE             1
OP/VEH/MAYS          1928
DIST. INCR.          .100
DCF:1              .16706
CONSTANT:1              0
COEF.:1           .015625

[7]M.P.   NET        CNT
B  0.000  00000032
I  0.100  0.100      108
I  0.200  0.100       89
I  0.300  0.100       67
I  0.400  0.099       64
I  0.500  0.099       57
E  0.593  0.093       81

NET LENGTH          0.593
ELAPSE TIME      00004320
TOTAL COUNT          466.

[5]  SUMMARY
BEGIN M.P.          0.000
END M.P.            0.593
NET LENGTH          0.593
ELAPSE TIME      00004320
TOTAL COUNT          466.
RIDE RATING          12.3

[4]
```

MAYS RIDE METER
MONTANA DEPARTMENT OF HIGHWAYS

SITE1-1 MONTANA

0.1001	0	0	ERR	11	12	49.1
0.167	0	0	ERR	11	12	53.9
0.2	0.0281	27	96.085	11	12	56.2
0.3004	0.1284	86	66.978	11	13	3.3
0.4003	0.2283	138	60.447	11	13	10.5
0.5	0.3281	181	55.166	11	13	17.6
0.5965	0.4246	242	56.995	11	13	24.5
0.6002	0.4283	245	57.203	11	13	24.8

SITE1-2 MONTANA

0	0	0	ERR	11	15	52.9
0.0248	0	0	ERR	11	15	55.3
0.1002	0.0704	62	88.068	11	16	1
0.2001	0.1703	123	72.225	11	16	8.1
0.3002	0.2704	191	70.636	11	16	15.2
0.4001	0.3703	237	64.002	11	16	22.3
0.5003	0.4705	286	60.786	11	16	29.4
0.5984	0.5686	343	60.324	11	16	36.4
0.6001	0.5702	346	60.680	11	16	36.6

SITE1-3 MONTANA

0.1001	0.1001	77	76.923	11	22	24.6
0.2001	0.2001	146	72.964	11	22	31.7
0.3	0.3	206	68.667	11	22	38.8
0.4001	0.4001	266	66.483	11	22	45.9
0.5	0.5	315	63.000	11	22	53
0.5973	0.5973	381	63.787	11	23	0
0.6002	0.6002	384	63.979	11	23	0.2

COX RAODMETER
NEVADA DEPARTMENT OF TRANSPORTATION

Run 1

DISTRI
RO
PR
ROAD METER
ODOM
MEN
SHOU
LTR

MI 11.9

RATING DIST

BEGIN DIST
ND DIST
OUNTS MI 7.5
PEED
RAVEL DIST .100
ATING DIST .100

EGIN DIST
ND DIST
OUNTS MI 8.2
PEED
RA
R DIST 0.100

BEGI 0.300
END 0.400
COUNTS MI 8.2
SPEED
TRAVEL DIST
RATING DIST

0.400
END 0.500
COUNTS 9.6
SPEED
TRAVEL DIST
RATING DIST

BEGIN DIST
END DIST
COUNTS MI 9.5
SPEED
TR EL DIST 0.100

B&K ACCELEROMETER
FHWA, WESTERN DIRECT FEDERAL DIVISION

-- B&K SLM TYPE 2231 --

Set Up: F. F. L.

MAXP	40.8 dB
MAXL	20.1 dB
MINL	7.4 dB
SEL	29.6 dB
LEQ	13.1 dB

No overload.

No reset of Max/Min.

Elapsed Time: 00:00:45

No. of interrupts: 0

-- B&K SLM TYPE 2231 --

Set Up: F. F. L.

MAXP	40.1 dB
MAXL	17.9 dB
MINL	6.8 dB
SEL	28.7 dB
LEQ	12.4 dB

No overload.

No reset of Max/Min.

Elapsed Time: 00:00:43

No. of interrupts: 0

-- B&K SLM TYPE 2231 --

Set Up: F. F. L.

MAXP	40.7 dB
MAXL	18.3 dB
MINL	6.3 dB
SEL	29.2 dB
LEQ	12.8 dB

No overload.

No reset of Max/Min.

Elapsed Time: 00:00:44

No. of interrupts: 0

PORTABLE UNIVERSAL ROUGHNESS DEVICE (PURD)
ONTARIO, CANADA

```
/erifying 871005AA.001 ...

HEADER:    'MTC-PURD   0000 1A @30MPH    131', chainage =      0

END OF FILE

Colavg: Produce IRI station summary information Ver 1.01  Sept 12/87
Copyright (c) 1986, 1987 by Highway Products International (HPI)

------------------------------------------------------------------
File '87A5aa01.hdr'
Processing samples 2048 to 6821 (413.61 to 1377.55 m)
    channel 4 is IRI in units of in/mi
        history: hpiiri   V1.51 87-10-05 20:14 (3>4)
------------------------------------------------------------------

IRI will be written to 87A5aa01.col in units of in/mi
```

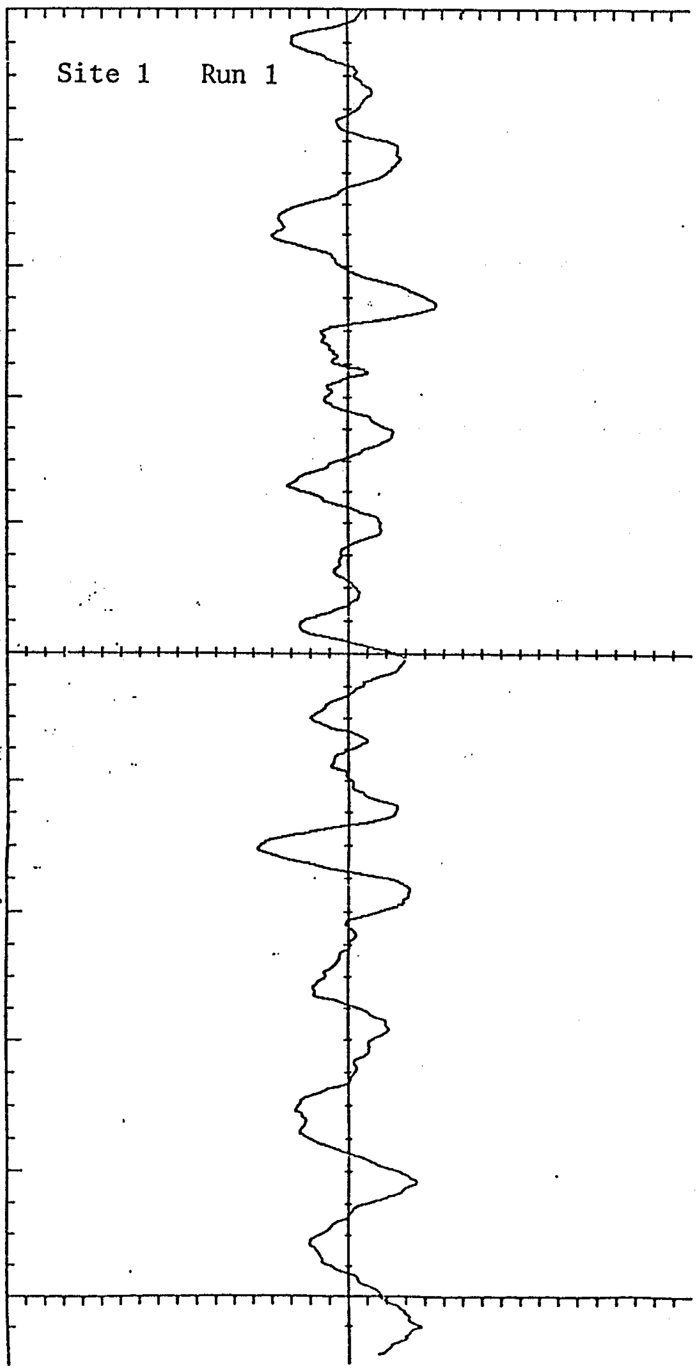
Chainage (miles)	IRI (in/mi)
0.100	98.21
0.200	83.03
0.300	75.77
0.400	70.21
0.500	69.14
0.600	68.59

Average IRI = 77.49 in/mi

Channel 3 of '87A5aa01'

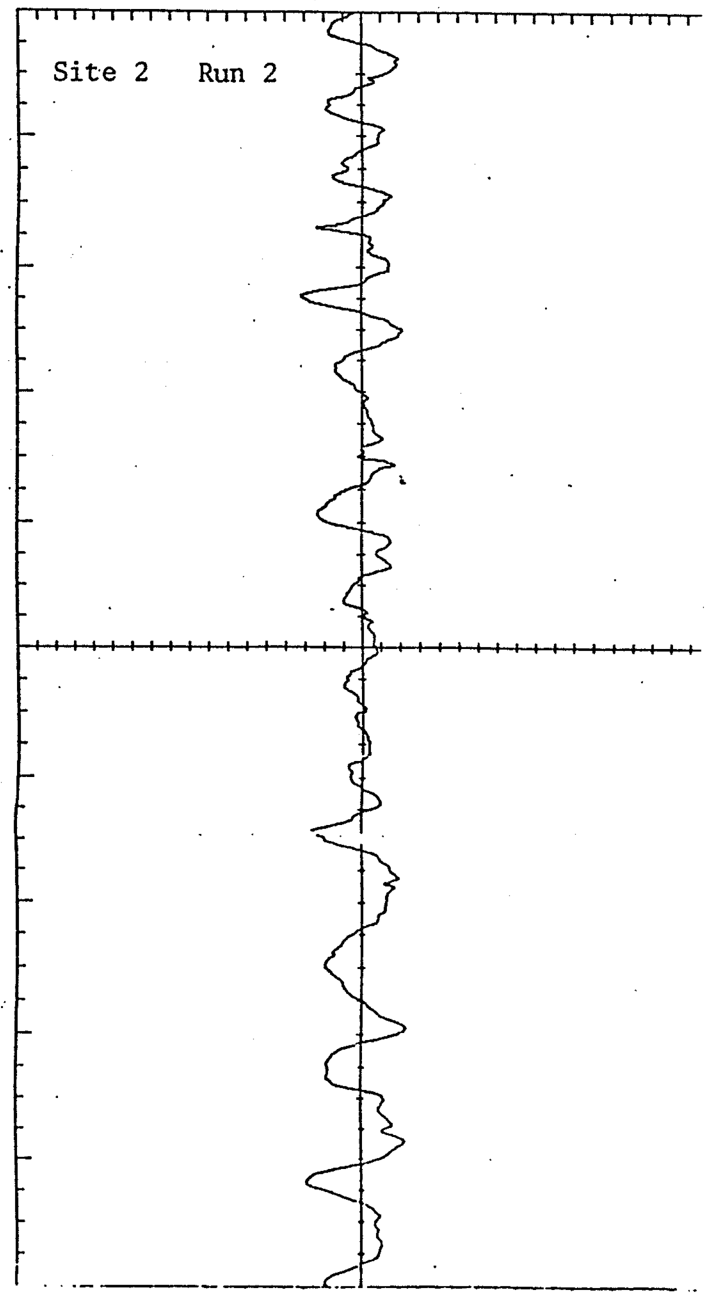
Title: ARAN3 Roughness Profile Data
Section: 871005aa.001
Date: 87/10/05
Speed: 13.63 m/s
history: hpiprof V3.31 87-10-05 20:13 (0,1,2)3)
Data is profile in units of mm from channel 3

Starting sample: 2476 (500.05 metres)
Ending sample: 6660 (1345.03 metres)
X axis scale: 20.0000 m / div
Y axis scale: 10.0000 mm / div



Title: ARAN3 Roughness Profile Data
Section: 871005aa.006
Date: 87/10/05
Speed: 19.80 m/s
history: hpiprof V3.31 87-10-05 20:24 (0,1,2)3)
Data is profile in units of mm from channel 3

Starting sample: 2476 (500.05 metres)
Ending sample: 7427 (1499.93 metres)
X axis scale: 20.0000 m / div
Y axis scale: 10.0000 mm / div



DYNATEST 5000
MISSISSIPPI HIGHWAY DEPARTMENT

```
R32  79  34  871005  TEST1m17R2!
1000070 45 .... 10000  20   50 !
2.0E4   .91  2    2    40   25 !
PRF     3    10    1000 250  40 !
1       TEST1                   !
I0       1   40   25 43 1000018 !
i.601    1   40   25 43 1000035 !
................0       .601    !
31  43  50                      !
Allg.Cracks AllC(V1)         V1!
EdgeDistrs. Edge(V2)         V2!
Pot Holes   Hole(V3)         V3!
Cover       CovrCover        Covr
Cracks      Crks(Skip)       SKIP
Ravelling   RvlgPvm.Shift    PShf
Patching    PtchSettling     Setl
Crossing    CrosCrossing     Cros
I0       1   40   25 43.100001419
3.3  30.5 21.4 65.3   4000000000
3.56 30.8 21.6 54.5   4000000000
3.72 30.7 20.0 48.3   4000000000
3.66 30.4 20.6 50.3   4000000000
3.55 30.7 20.4 54.8   4000000000
3.6  30.5 21.2 52.5   4000000000
3.64 30.8 21.8 51.6   4000000000
3.59 30.6 21.4 53.1   4000000000
3.5  30.9 20.8 57.1   4000000000
3.66 30.8 18.8 50.6   4000000000
3.58 30.6 21.5 53.4   4000000000
3.66 30.6 19.8 50.3   4000000000
3.58 30.7 22.4 53.5   4000000000
3.55 30.5 20.5 54.4   4000000000
3.55 30.6 22.6 54.9   4000000000
i   0.601  10   1   0           !
EOF                             !
```

SELF-CALIBRATING ROUGHNESS DEVICE (SIometer)
TEXAS HIGHWAY DEPARTMENT

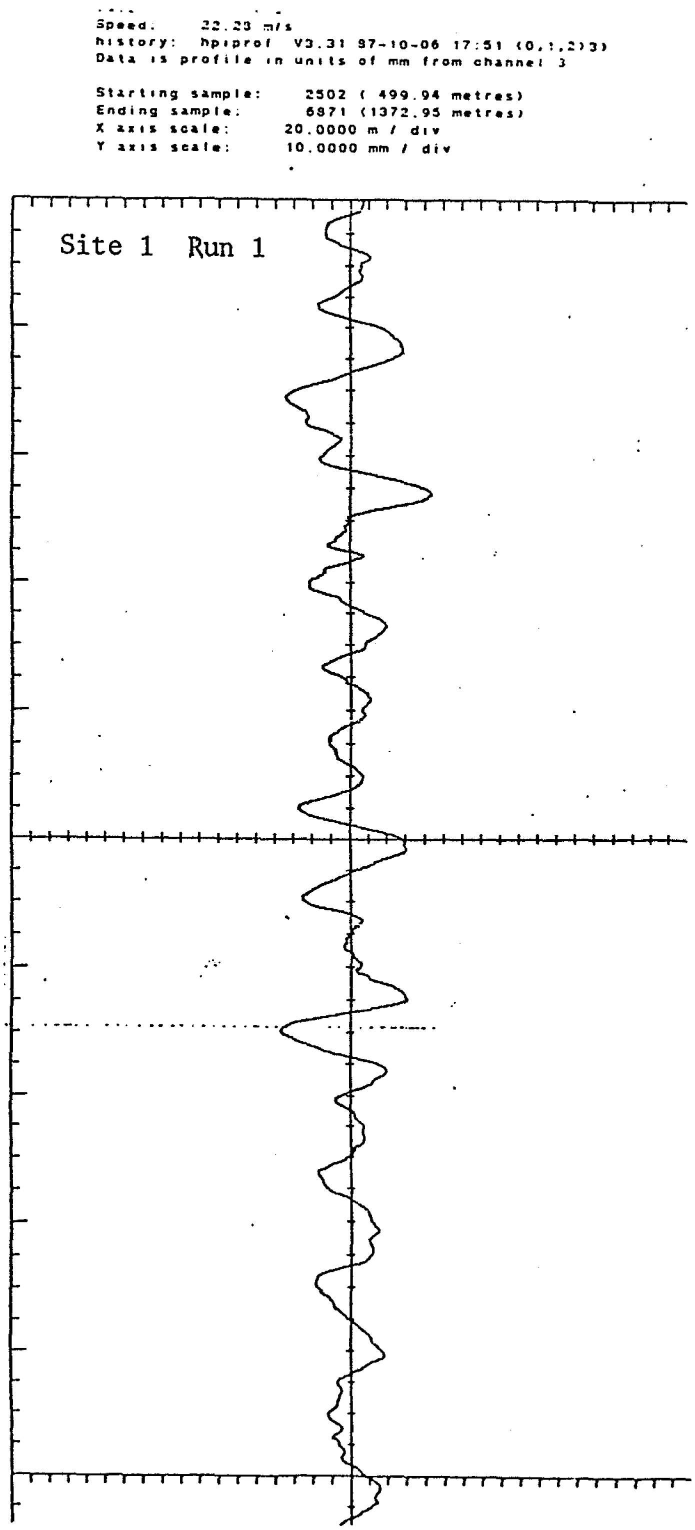
SECTION #	RUNS				SPEED ( )
	1	2	3	4	
	(50)	(50)	(30)	(30)	
1	2.5	2.6	2.6	2.5	50-30
	3.8	3.8	3.8	3.8	
	3.6	3.7	3.7	3.9	
	(50)	(30)	(50)	(30)	
2	2.3	2.4	2.5	2.4	50-30
	2.6	2.7	2.8	2.7	
	3.4	3.5	3.6	3.4	
	2.5	2.7	2.7	2.7	
	(50)	(50)	(50)		
3	3.8	3.1	3.6		50
	3.7	3.4	3.8		
	4.0	3.9	3.8		
	3.1	3.2	3.1		
	(50)	(50)	(50)		
4	2.1	2.1	2.1		50
	2.0	2.3	2.2		
	2.5	2.6	2.6		
	2.3	2.4	2.4		
	(30)	(30)	(30)	(45)	(45)
5	1.7	1.8	1.8	2.0	2.1
	1.1	1.2	1.3	.8	.8
	1.5	1.3	1.3	1.5	1.5
	2.4	2.4	2.4	2.4	2.4

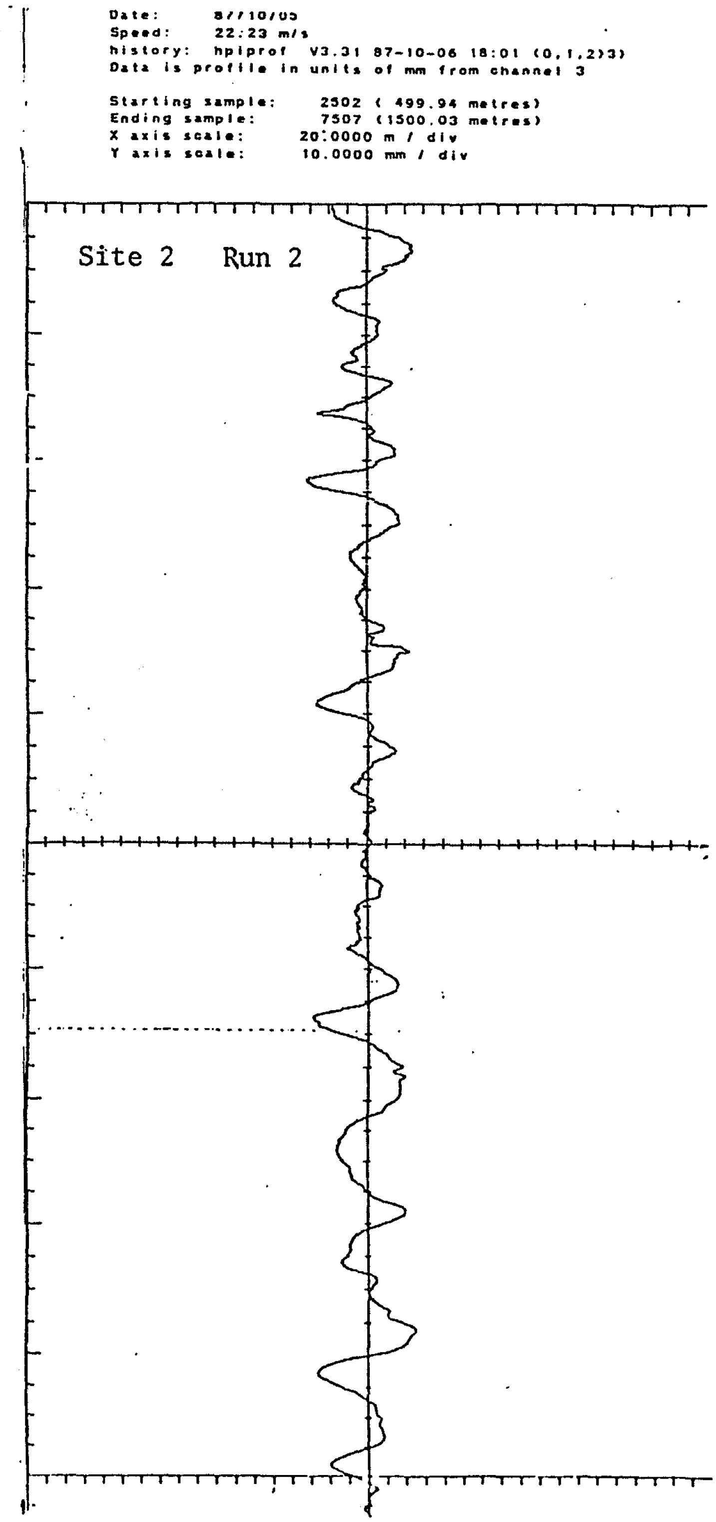
AUTOMATIC ROAD ANALYZER (ARAN III)
TEXAS HIGHWAY DEPARTMENT

```
Verifying 871005AD.001 ...

HEADER:     '2 ARAN 15        SH068S  01  1L2', chainage =      0

END OF FILE

Colavg: Produce IRI station summary information Ver 1.01  Sept 12/87
Copyright (c) 1986, 1987 by Highway Products International (HPI)

------------------------------------------------------------------
File '87A5ad01.hdr'
Processing samples 2048 to 6926 (409.23 to 1383.94 m)
    channel 4 is IRI in units of in/mi
        history: hpiiri   V1.51 87-10-06 17:52 (3)4)
------------------------------------------------------------------

IRI will be written to 87A5ad01.col in units of in/mi
```

Chainage (miles)	IRI (in/mi)
0.100	96.73
0.200	79.20
0.300	75.74
0.400	69.55
0.500	63.12
0.600	71.79

Average IRI = 76.02 in/mi


Speed: 22.23 m/s
history: hpiprof V3.31 87-10-06 17:51 (0,1,2)3)
Data is profile in units of mm from channel 3
Starting sample: 2502 (499.94 metres)
Ending sample: 6871 (1372.95 metres)
X axis scale: 20.0000 m / div
Y axis scale: 10.0000 mm / div
Site 1 Run 1


Date: 87/10/05
Speed: 22.23 m/s
history: hpiprof V3.31 87-10-06 18:01 (0,1,2)3)
Data is profile in units of mm from channel 3
Starting sample: 2502 (499.94 metres)
Ending sample: 7507 (1500.03 metres)
X axis scale: 20.0000 m / div
Y axis scale: 10.0000 mm / div
Site 2 Run 2

ROUGHNESS SURVEYOR , K.J.LAW M8300
NEBRASKA DEPARTMENT OF ROADS

K.J. LAW ENGINEERS INC. ROUGHNESS SURVEYOR MODEL 8300

MONDAY 10/05/87 16:15:07

RUN NUMBER: 1
ROAD DESCRIPTION: SITE 1
DIRECTION MEASURED: WB
LANE: OWP
BEGINNING MILEPOST:
MILEPOST DESCRIPTION:
SIMULATED SPEED (MPH): 50.0

MILEPOST	DISTANCE TRAVELED	MAYS INDEX	RMSA INDEX
	0.101	111	21.4
	0.199	95	16.8
	0.300	57	10.7
	0.402	66	12.6
	0.499	60	10.7
	0.601	75	13.2

ROUGHNESS SURVEYOR , K.J.LAW M8300
COLORADO DEPARTMENT OF HIGHWAYS

K.J. LAW ENGINEERS INC. ROUGHNESS SURVEYOR MODEL 8300

MONDAY 10/05/87 13:26:19

RUN NUMBER:	1
ROAD DESCRIPTION:	SH 68
DIRECTION MEASURED:	WB
LANE:	2
BEGINING MILEPOST:	0.000
MILEPOST DISCRIPTION:	SITE #1
SIMULATED SPEED (MPH):	50.0

MILEPOST	DISTANCE TRAVELED	MAYS INDEX	RMSA INDEX
	0.101	82	17.3
	0.199	79	14.7
	0.300	46	9.0
	0.402	64	12.7
	0.499	48	8.6
	0.601	61	10.4

63 AV.

LASER ROAD SURFACE TESTER (LASER RST)
INFRASTRUCTURE MANAGEMENT SERVICES, ILLINOIS

COLORADO TEST 01 LN-2 HARMONY RD

	1	SP			Mo
1	161	161	44	1.5	1.1
1	322	322	45	1.2	0.7
1	483	483	44	0.9	0.5
1	644	644	43	1.1	0.8
1	805	805	41	1.0	0.4
1	963	963	42	1.0	0.4
1	963	963	43	1.1	0.7

mm/m 63.36 1/mi

2 ND RUN 1

2	161	161	43	1.7	1.8	0	0	0								
2	322	322	43	1.2	0.7	0	0	0								
2	483	483	43	0.9	0.5	0	0	0								
2	644	644	44	1.1	0.8	0	0	0								
2	805	805	44	0.9	0.4	0	0	0								
2	966	966	44	1.0	0.5	0	0	0								
2	980	980	45	1.1	0.4	0	0	0								
2	980	980	43	1.2	0.9	0	0	0	2	1	1	2	1	1	1	1

3 RD RUN 1

K.J.LAW 690 PROFILOMETER
FHWA,McLean,VA

File Name: MS0:PPS001.001

Base Log Number: 0.0000

1

10/3/77
2:55 - 3:10
L+R Comb

Log Number (Miles)	Feet from Start	MAYS Index (In/Mile) @ 30. MPH	PCA Index (Cnts/Mile) @ 30. MPH	PSI	RMS Accel Sprung Mass (G's*1000) @ 30. MPH
0.1000	528.0	88.0	2110.	3.7817	12.0
0.2000	1056.0	77.3	1150.	3.7868	10.1
0.3000	1584.0	76.8	780.	3.7605	10.6
0.4000	2112.0	73.9	830.	3.7297	10.1
0.5000	2640.0	71.6	610.	3.6646	9.8
0.6000	3168.0	89.5	1180.	3.6459	11.8

File Name: MS0:PPS001.002

Base Log Number: 0.0000

L+R Comb

Log Number (Miles)	Feet from Start	MAYS Index (In/Mile) @ 30. MPH	PCA Index (Cnts/Mile) @ 30. MPH	PSI	RMS Accel Sprung Mass (G's*1000) @ 30. MPH
0.1000	528.0	88.3	2190.	3.7830	11.9
0.2000	1056.0	79.3	1290.	3.7605	10.5
0.3000	1584.0	70.9	700.	3.7210	9.9
0.4000	2112.0	70.7	840.	3.7824	9.7
0.5000	2640.0	70.9	640.	3.6880	10.1

File Name: MS0:PPS001.003

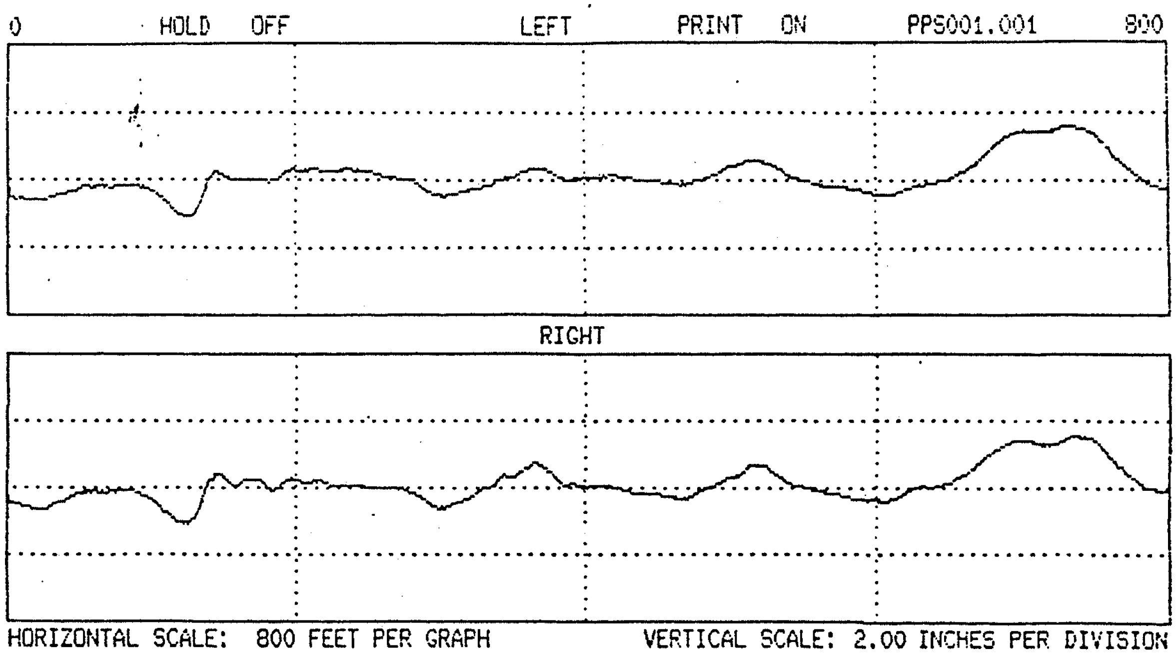
Base Log Number: 0.0000

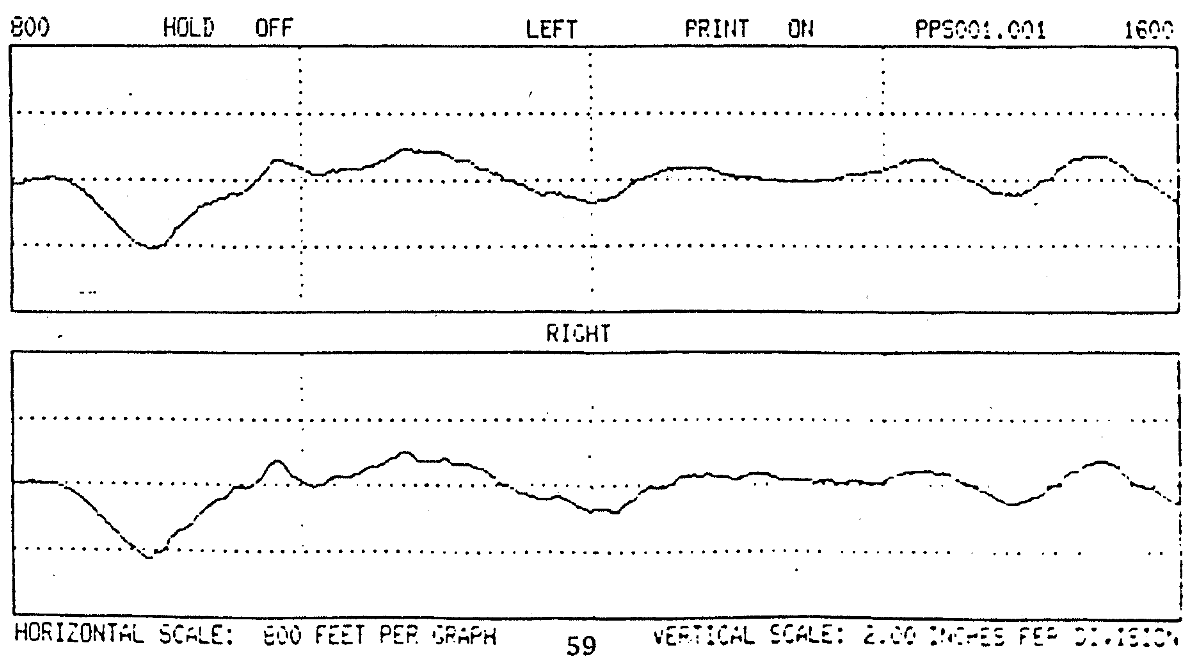
L+R Comb

Log Number (Miles)	Feet from Start	MAYS Index (In/Mile) @ 30. MPH	PCA Index (Cnts/Mile) @ 30. MPH	PSI	RMS Accel Sprung Mass (G's*1000) @ 30. MPH
0.1000	528.0	90.1	2150.	3.8036	12.2
0.2000	1056.0	75.4	1150.	3.8140	9.9
0.3000	1584.0	72.9	660.	3.8136	10.0
0.4000	2112.0	69.7	810.	3.8090	9.5
0.5000	2640.0	72.7	730.	3.6861	10.3
0.6000	3168.0	88.1	1280.	3.7087	11.7

Site #1

K.J.LAW 690 DNC





PRO RUT
FHWA

LISTING OF UMTRI DATA FILES
Bad command or file name

A:\>TYPE S-1-1R.NUM

DISTANCE - FEET FROM...		TO	L. IRI IN/MI	R. IRI IN/MI	C. RUT INCH
.00	-	528.00	86.04	110.65	.09
528.00	-	1056.00	82.02	100.63	.11
1056.00	-	1584.00	60.60	89.99	.11
1584.00	-	2112.00	74.13	90.27	.13
2112.00	-	2640.00	64.91	75.32	.13
2640.00	-	3139.50	75.06	91.74	.11

A:\>
A:\>
A:\>TYPE S-1-2.NUM

DISTANCE - FEET FROM...		TO	L. IRI IN/MI	R. IRI IN/MI	C. RUT INCH
.00	-	528.00	87.85	119.15	.05
528.00	-	1056.00	82.58	102.75	.13
1056.00	-	1584.00	59.67	84.04	.16
1584.00	-	2112.00	72.50	90.61	.18
2112.00	-	2640.00	62.83	74.14	.16
2640.00	-	3120.00	75.77	97.64	.10

A:\>TYPE
A:\>
A:\>TYPE S-1-3.NUM

DISTANCE - FEET FROM...		TO	L. IRI IN/MI	R. IRI IN/MI	C. RUT INCH
.00	-	528.00	86.90	111.69	.06
528.00	-	1056.00	83.23	104.59	.14
1056.00	-	1584.00	60.58	85.68	.15
1584.00	-	2112.00	71.34	91.70	.18
2112.00	-	2640.00	63.56	76.93	.16
2640.00	-	3150.00	74.95	94.98	.13

ROAD PROFILER
SOUTH DAKOTA

South Dakota Road Profiler: Left wheel profile

Date	Time	Loc	Run	Speed	Lane	Project Description
05-OCT-87	09:23:59	0001	001	47.7	1	DEMO.72,SITE #1

MRM	Dsp	IRI(in/mi)
00100	+0000	096
00100	+0100	094
00100	+0200	076
00100	+0300	082
00100	+0400	070
00100	+0500	078

Date	Time	Loc	Run	Speed	Lane	Project Description
05-OCT-87	09:30:33	0001	002	47.7	1	DEMO.72,SITE#1

MRM	Dsp	IRI(in/mi)
00100	+0000	130
00100	+0100	099
00100	+0200	070
00100	+0300	076
00100	+0400	071
00100	+0500	078

Date	Time	Loc	Run	Speed	Lane	Project Description
05-OCT-87	09:34:57	0001	003	50.1	1	DEMO 72,SITE #1

MRM	Dsp	IRI(in/mi)
00100	+0000	097
00100	+0100	098
00100	+0200	075
00100	+0299	079
00100	+0399	077
00100	+0499	084

S.DAKOTA ROAD PROFILER
NEBRASKA DEPARTMENT OF ROADS

Nebraska/SD Road Profiler: Left wheel path profile

Date	Time	Loc	Run	Speed	Lane	Project Description
05-SEP-87	04:15:18	0001	001	31.9	1	#1-1

MRM	Dsp	IRI(in/mi)
00100	+0000	141
00100	+0101	141
00100	+0202	136
00100	+0303	130
00100	+0403	128
00100	+0504	106

Date	Time	Loc	Run	Speed	Lane	Project Description
05-SEP-87	04:22:54	0001	002	30.7	1	#1-2

MRM	Dsp	IRI(in/mi)
00100	+0000	151
00100	+0100	138
00100	+0199	124
00100	+0299	132
00100	+0399	116
00100	+0499	095

Date	Time	Loc	Run	Speed	Lane	Project Description
05-SEP-87	04:25:40	0001	003	30.4	1	#1-3

MRM	Dsp	IRI(in/mi)
00100	+0000	143
00100	+0099	150
00100	+0199	133
00100	+0298	137
00100	+0398	133
00100	+0497	120

TEXAS SURFACE PROFILOMETER
TEXAS HIGHWAY DEPARTMENT

1056 FT. SECTION BEGINS 0 FT. FROM MARK 0 IN FILE d:1a

STEP: 0.11 IN. AT 120.5 FT.

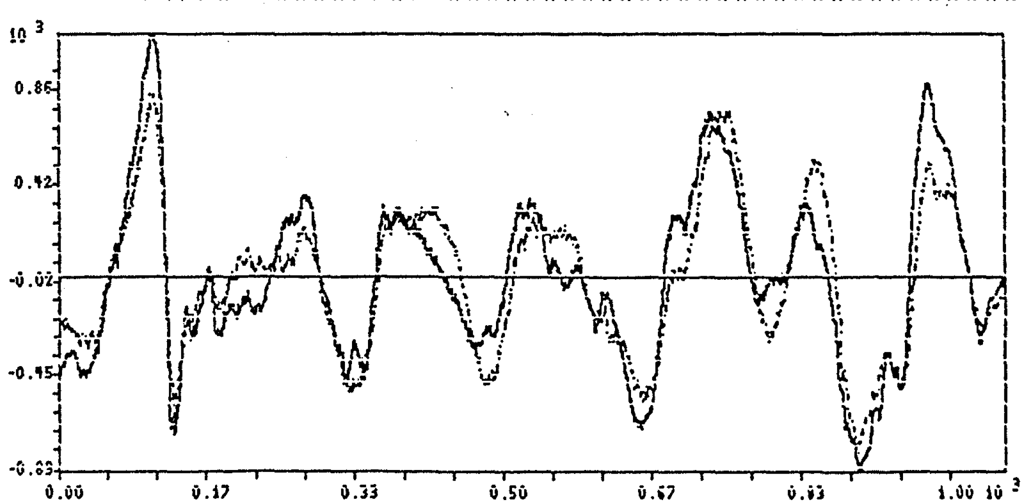
BASE LENGTH	RIGHT	LEFT	COMBINED	ESTIMATED SI
0.5	29.62	43.48	36.55	3.25
1.0	13.37	14.51	13.94	3.64
2.0	4.61	4.56	4.58	4.29
4.0	2.14	1.71	1.93	4.01
8.0	1.32	0.91	1.11	3.11
16.0	0.73	0.58	0.66	2.64
32.0	0.33	0.30	0.32	2.61
64.0	0.13	0.12	0.12	2.81
128.0	0.02	0.02	0.02	3.47

MO (MRM SIMSTAT) (COUNTS/.2 MILE): 55.80

FLEXIBLE PAVEMENT SERVICEABILITY: 3.68

New PSI: 4.17

****



From: 1.0 To: 1056.5
Commands: (SPACE) Draw profile Print profile Printing...

****

APPENDIX A

EQUIPMENT OPERATORS

LIST OF EQUIPMENT OPERATORS

EQUIPMENT NAME & OWNER	OPERATOR NAME	ADDRESS
Rainhart Profilograph Colorado DOH	David A. Price	Colorado Dept. of Highways 4201 E. Arkansas Ave. Denver, CO 80222
McCracken Profilograph Colorado DOH	William Outcalt	Colorado Dept. of Highways 4201 E. Arkansas Ave. Denver, CO 80222
Dipstick E. W. Face Co.	Walter G. Rooke	Edward FAce Co. 200 - 5 Donald Winnipeg,Manitoba,CAN R3L2T4
Ames Profilograph Central Direct Federal Div.	Allan S. Miller	Central Direct Division Federal Highway Admin. 555 Zang Street Lakewood, CO 80228
Mays Ridemeter Wyoming Highway Dept.	Tom Adkins	Wyoming Highway Dept. Box 1708 Cheyenne, WY 82002
Mays Ridemeter Montana DOH	Dave Routzahn	Montana Dept. of Highways 2701 Prospect Helena, MT 59620
Cox Roadmeter Nevada DOT	Chuck Cook	Nevada Dept. of Trans. 1263 S. Stewart Carson City, NV 89712
B&K Accelerometer Western Direct Federal	William McLoughlin	Western Direct Div. Federal Hwy. Admin. 610 E. 5th Street Vancouver, WA 98661
H.P.I. PURD Ontario M.T.C.	Frank Speers	Hwy. Products Internat'l. Box 520 Paris, Ont. CAN N3L3T6
Dynatest RDM Mississippi Hwy. Dept.	Al Crawley	Mississippi Hwy. Dept. Box 1850 Jackson, MS 39215
Texas Self Calibrating Roughness Unit Texas DOH & Pub. Trans.	Randy Beck	Texas DOH & Pub. Trans. Box 5051 Austin, TX 78763
Aran III Texas DOH & Public Trans.	Gary Cypert	Texas DOH & Pub. Trans. Box 5051 Austin, TX 78763

LIST OF EQUIPMENT OPERATORS (Continued)

EQUIPMENT NAME & OWNER	OPERATOR NAME	ADDRESS
K. J. Law M8300 Nebraska Dept. of Roads	George Woolstrum	Nebraska Dept. of Roads Box 94759 Lincoln, NE 68509
K. J. Law M8300 Colorado DOH	Robert Olejnik	Colorado Dept. of Hwys. 4201 E. Arkansas Ave. Denver, CO 80222
Laser RST IMS Infrastructure Mgmt. Services	Robert Novak	IMS Infrastructure Mgmt. 3350 Salt Creek #117 Arlington Heights, IL 60005
K. J. Law 950 DNC Profilometer FHWA	Peter Spellerberg	AMRL NBS Bldg. 226, Rm. A365 Gaithersburg, MD 20899
Pro Rut System FHWA	Loren Staunton	Federal Highway Admin. 6300 Georgetown Pike HNR-20 McLean, VA 22101
Road Profilometer South Dakota DOT	David Huft	South Dakota DOT 700 Broadway East Pierre, SD 57501
SD Profilometer Nebraska DOR	Gary Brhel	Nebraska Dept. of Roads Box 94759 Lincoln, NE 68509
Texas Surface Dynamics Profilometer Texas DOH & Pub. Roads	Robert Light	Texas DOH & Pub. Roads Box 5051 Austin, TX 78763

APPENDIX B

DETAILED EQUIPMENT REPORTS

RAINHART PROFILOGRAPH
COLORADO DEPARTMENT OF HIGHWAYS

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

EQUIPMENT REPORT

RAINHART PROFILOGRAPH

A. The Rainhart Profilograph is composed of 12 wheels mounted on a frame to provide an average reference plane. There is one main frame, two intermediate frames, and four wheelframes each with three wheels mounted at the points of the triangle. The main frame rests on the two intermediate frames and each intermediate frame rests on two wheel frames. The wheels are aligned so that no two wheels follow the same path. This arrangement minimizes the effect of localized bumps on the reference frame. Mounted on the main frame is the measuring wheel which is 19 inches in diameter providing a 5 foot travel per revolution. The strip chart recorder records vertical movement of the wheel with respect to the reference frame. Advancement of the chart is accomplished by a chain drive coupled to the measuring wheel. For vertical wheel movement, one inch of deflection on the chart is equivalent to 1 inch on the roadway. The chart distance scale can be selected for 10 feet/inch or 25 feet/inch. The pen may be positioned to write anywhere on the chart and the chart drive can be reversed if required.

Three digital counters mounted on the recorder housing are used. One counter is coupled to the chart drive and accumulates feet of travel. Two additional counters are used to accumulate a roughness statistic. The left counter advances whenever the wheel moves down more than 0.1 inches accumulating total rectified vertical displacement. The right counter is connected through a ratchet with a 0.2 inch backlash causing only fluctuations in excess of 0.2 inch to be accumulated. Because of the high inertia of the wheel and linkage, the machine should not be operated faster than at a slow walk (2 mph) speed.

B. The Rainhart profilograph measures roughness in 1/10 of an inch. A chart drive is located within the recording unit where a pen is used to record actual roughness on a scale of 1:1. The two statistical counters discussed in A allow an immediate result to be seen, while the chart must be taken back to the office to reduce the profile into a number that can be understood. All counter data must be manually recorded.

C. Rainhart Basic Catalog (1981), Testing Equipment puts a price of $7660.00 on this particular profilograph. This price is for the complete unit.

D. Based on a Research report written by Richard Griffin in 1984 entitled "Acceptance Testing for Roadway Smoothness" the cost of testing can be expected to be about $50 per mile. This breaks down to $40 for operation and traffic control while $10 is for equipment maintenance and depreciation.

E. 1. Setup of the Rainhart Profilograph consists of mounting the twelve averaging wheels and placing the recording box on the main frame. The setup procedure requires approximately 10 minutes to complete. Due to the slow speed required to operate the profilograph traffic control is a requirement.

2. For ease of operating a minimum of two individuals are required. This breaks down to one person steering and making notes on the chart located in the recording unit while the other powers the movement.

3. This profilograph has been used by other agencies at a project level for determination of roadway smoothness.

4. Speed of the profilograph in limited to a slow walk approximately 2 mph limiting the size of projects to be tested. Manual data reduction is time consuming and can become a major disadvantage.

5. The Rainhart Profilograph is fairly simple producing few technical problems that can not be solved by the operator. However, the manufacturer has been very cooperative when questions have arisen.

6. Durability was found to be good when used basically in one area without a lot of travel. Most problems with durability were found to be due to extensive travel throughout the state. Repeatability was found to be good on smooth pavements but suffered on rough.

7. N/A

8. Minimum on site training is required to operate the profilograph.

9. This machine is used fairly excessively for monitoring asphalt and concrete research studies.

10. Average costs of data collection: $50 / mile Average costs of analysis and reporting: $3 / mile
Total costs: $53 / mile

11. Due to the slow speed that the profilograph must be run, 8 miles per day can be the expected productivity. This is 8 miles in one wheel path.

12. N/A

13. N/A

14. The recording unit on the Rainhart Profilograph is equipped with two statistical counters for reporting actual roughness in inches. One counter measures total roughness while the other contains a 1/10 inch filter eliminating aggregate or deformations on the pavement less than 1/10 of an inch. For Research purposes it was decided that 1/10 and 2/10 inch filters would produce a more realistic statistic for roadway smoothness than the no filter and the 1/10 filter arrangement. So the counter with no filter was modified with a 2/10 inch filter, allowing the new arrangement of the two counters to consist of one with a 1/10 filter and the other a 2/10.

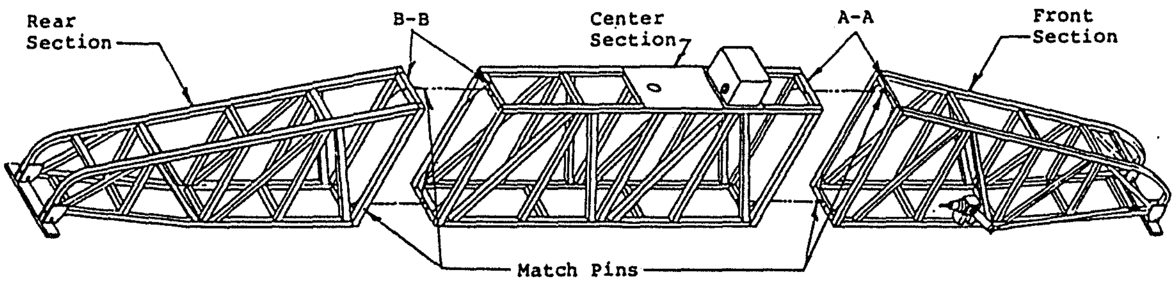
McCRACKEN PROFILOGRAPH
COLORADO DEPARTMENT OF HIGHWAYS

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

PREFACE

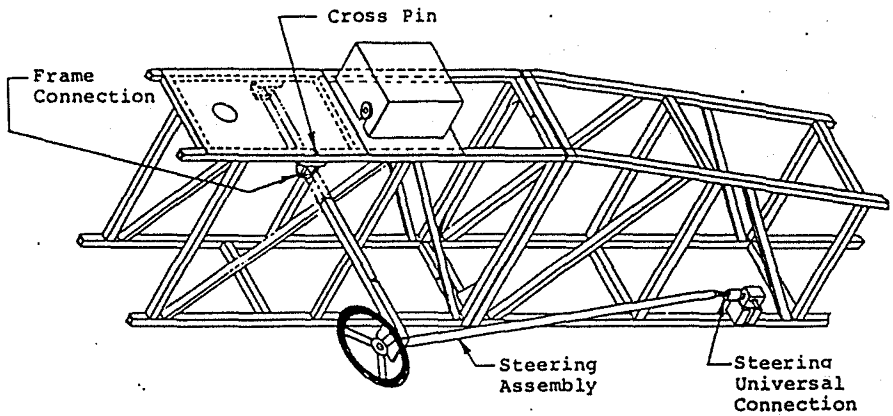
This manual has been prepared for those persons involved in the operation of the McCracken Profile Reader. The following steps contain information on field assembly, operation, adjustments and maintenance. Assembly drawings and part lists are enclosed in the rear of this manual.

PROFILE READER ASSEMBLY INSTRUCTIONS



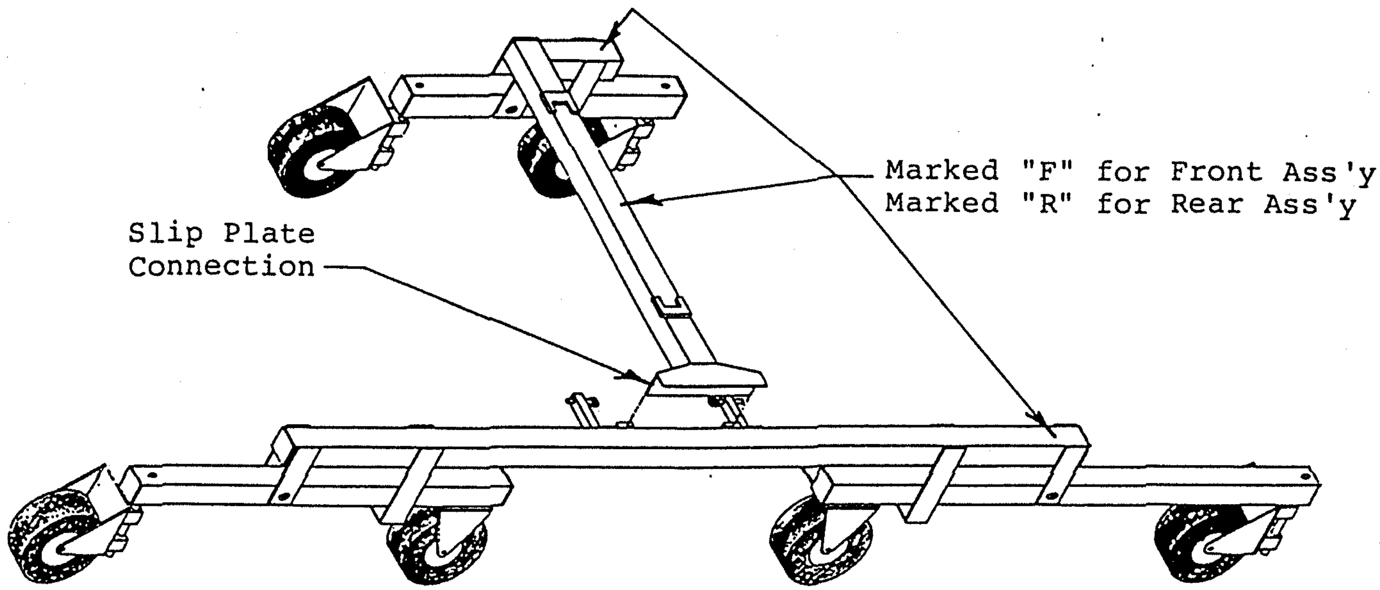
STEP 1: JOIN FRAME SECTIONS

1. Place frame sections on floor as shown above.
2. Arrange sections according to letter match markings (A-A and B-B).
3. Align match pins and slide sections toqether.
4. Secure with clamps provided.



STEP 2: STEERING CONNECTION

1. Insert steering universal connection to steering tube.
2. Swing steering support into frame connection.
3. Slide support through both frame brackets.
4. Aliqn holes & insert cross pin.



STEP 3: FRONT & REAR WHEEL ASSEMBLY

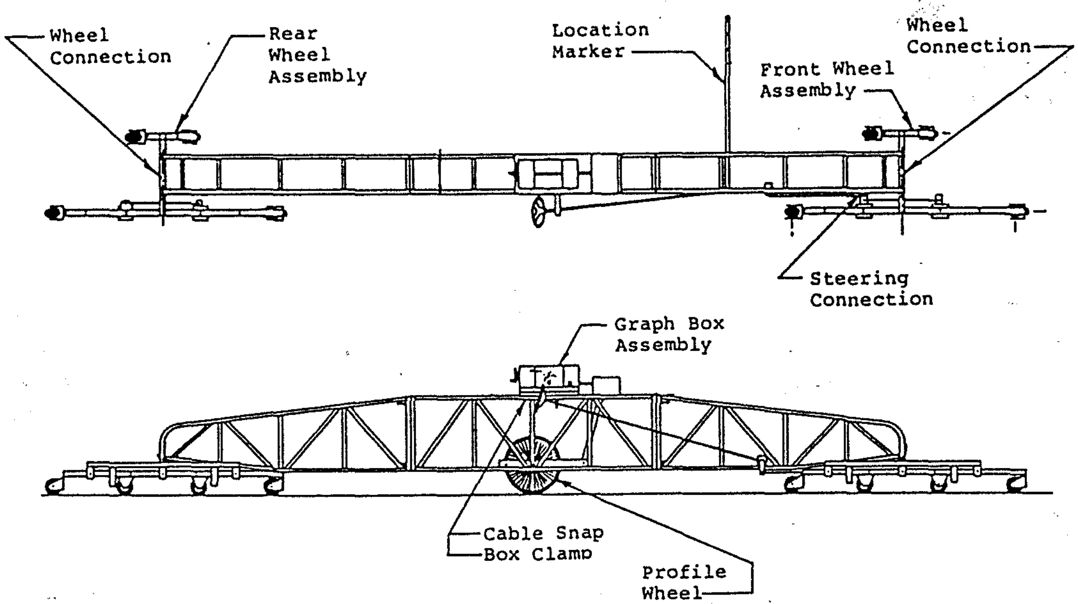
1. There are two (2), six castor wheel assemblies; a front assembly and a rear assembly.

2. Seperate the parts according to the letter marking each piece.

3. Position the "F" parts as shown above.

4. Slide the connecting plate into the mating retainer clips and secure with the clamp provided.

5. Repeat procedure #3 and #4 with the "R" parts.



STEP 4: FINAL ASSEMBLY

1. Position front & rear wheel assemblies as shown.

2. Lift front of frame and set the hinged flat into the nesting area provided on top of the wheel frame.

3. Secure connection with clamps.

4. Repeat this procedure for rear wheel connection.

5. Remove the tie rod end from its transport position and secure it on the steering caster bolt.

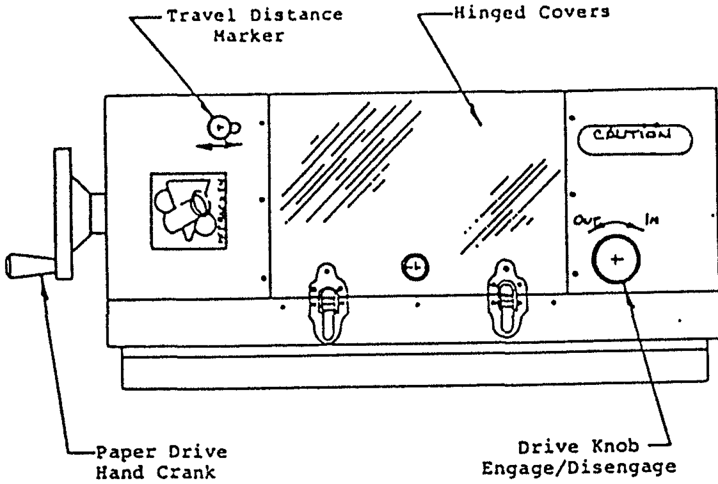
6. Set the graph recorder box on the frame with the crank handle toward the rear. Loosen the box clamp bolt located under the top plate on the frame. Coordinating the clamp bolt, the frame pin and the drive gear teeth, slide the graph box in place and tighten the clamp bolt to secure.

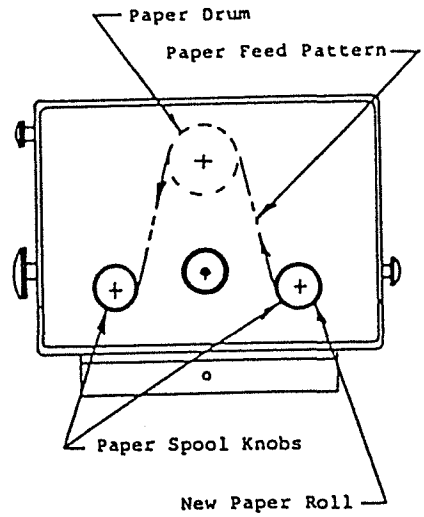
7. Connect the cable snap under the graph box to the yoke cable on the profile wheel.

8. Slide the location marker rod into frame brackets and secure with cross pin. Insert marker wire at the desired width distance.

STEP 5: BECOMING FAMILIAR WITH --

"THE GRAPH RECORDER ASSEMBLY"





The graph recorder requires no additional assembly and is ready for service when it is set in place on the frame and connected. (Refer to Step 4, Item #6)

CONTROLS

1. Drive Knob - Engage/Disengage

   Turning this knob clockwise connects gearing which transmits the profile wheel rotation to the graph recorder assembly.

   Turning this knob counterclockwise disconnects the profile wheel drive and allows the paper drum to rotate freely by turning the paper drive hand crank.

2. Paper Drive Hand Crank

   This is used for manual paper feed, usually during loading or removal of graph paper. CAUTION: Make sure to disengage drive knob before turning paper drive hand crank.

3. Paper Spool Knobs

   The paper spool knobs assist in loading and removing the graph paper rolls. They are also used to manually remove excessive paper slack which may occur during paper loading. Note the position of the new paper roll and the feed direction pattern. (Use paper roll #5701, manufactured by Graphic Control Corp.)

STEP 5: (CONTINUED)

4. Travel Distance Marker

   The marking device uses a pen to record a base line on the left side of the graph paper. When the marker knob is moved from side to side a "cross" mark is made on the graph paper. This cross mark can be used to indicate the beginning or end of an examined area. By opening the graph assembly cover, the cross marks can be noted with specific reference information such as area, location, distance or direction. The distance recroded on the graph paper is 1:300 the surface traveled by the profile wheel. (i.e., a graph length marked 10" long represents 3000" (250'-0") traveled by the profile wheel. This calibraton is preset and locked at the factory. (Refer to Step 6, Item #2, Calibration Adjustment)

5. Profile Marker Pen

   Located in the center/right of the graph assembly is the profile marker pen. It is mechanically attached to the profile wheel by a cable connection. As the profile wheel raises the marker moves right; as the wheel lowers the marker moves left. Movement ratio is 1:1 (i.e., the wheel raises ½", the marker moves right ½"). This linkage therefore makes possible the recording of surface changes on the graph paper as the profile wheel travels over the surface contour.

6. Marker Pens

   Both the travel distance marker and the profile marker use standard ball point pen refills. The refills will require bending for case clearance. Several spare refills are recommended and the pressurized type is best for use in cold weather.

7. Maintenance

   The graph recorder is constructed mostly from aluminum material, however, there are steel components used where aluminum was impractical. Inspect the sprockets, chains, gears and shafts. Components with rust should be cleaned and protected with a light coat of oil. Inspect the set screws and tighten those which have become loose. Daily dust removal is recommended. Compressed air can be used for this purpose.

STEP 6: MAINTENANCE AND ADJUSTMENTS

1. The Profile Wheel

   This component is preassembled and installed in the center frame from the factory. Air pressure is to be maintained at 25PSI for consistent graph recording (check daily). A 24" x 1.75 Schwinn wheel with tire and tube is used. The tire surface has been ground to insure its roundness. Tire surface irregularities that develop through wear can be removed by regrinding. Replacement tires will require the rounding process and calibration.

2. Calibration

   Graph length represents traveled distance at a reduction of 1:300. This means as the paper advances 1" the profile wheel has actually traveled or rolled 300" or 25 feet. Varying tire circumference directly affects this ratio. A variable reducer is used in the drive line allowing each Profile Reader to be adjusted or calibrated individually to the 1:300 ratio. Tire wear or replacement will make necessary unit recalibration.

   To check or recalibrate, measure and mark off a straight distance of 500 feet on a smooth paved surface. Operate the Profile Reader on this predetermined test area. The graph length should be 20" long. If the graph length is not within local requirements, recalibration is suggested. Remove the front cover from the calibration box located on the top of the center frame. Behind this cover is the variable reducer, fitted with a hand crank and a lock screw. If less graph is needed, turn hand crank counter-clockwise 1/16 of a turn at a time and put tension on set screw and arm. If more graph is needed release the tension on set screw and turn hand crank clockwise 1/16 turn at a time and put tension on set screw. There is a direction decal on the hand crank. For final adjustment, no more than 1/16" in majority of cases can be done just by tweaking the set screw. tweak set screw clockwise for less graph and counterclockwise for more graph. Reset the lock screw after each adjustment. Several test runs will probably be necessary for accurate recalibration. Use a moderate walking speed and steer the unit as straight as practical. This practice minimizes wheel bounce and slippage which cause inferior recordings.

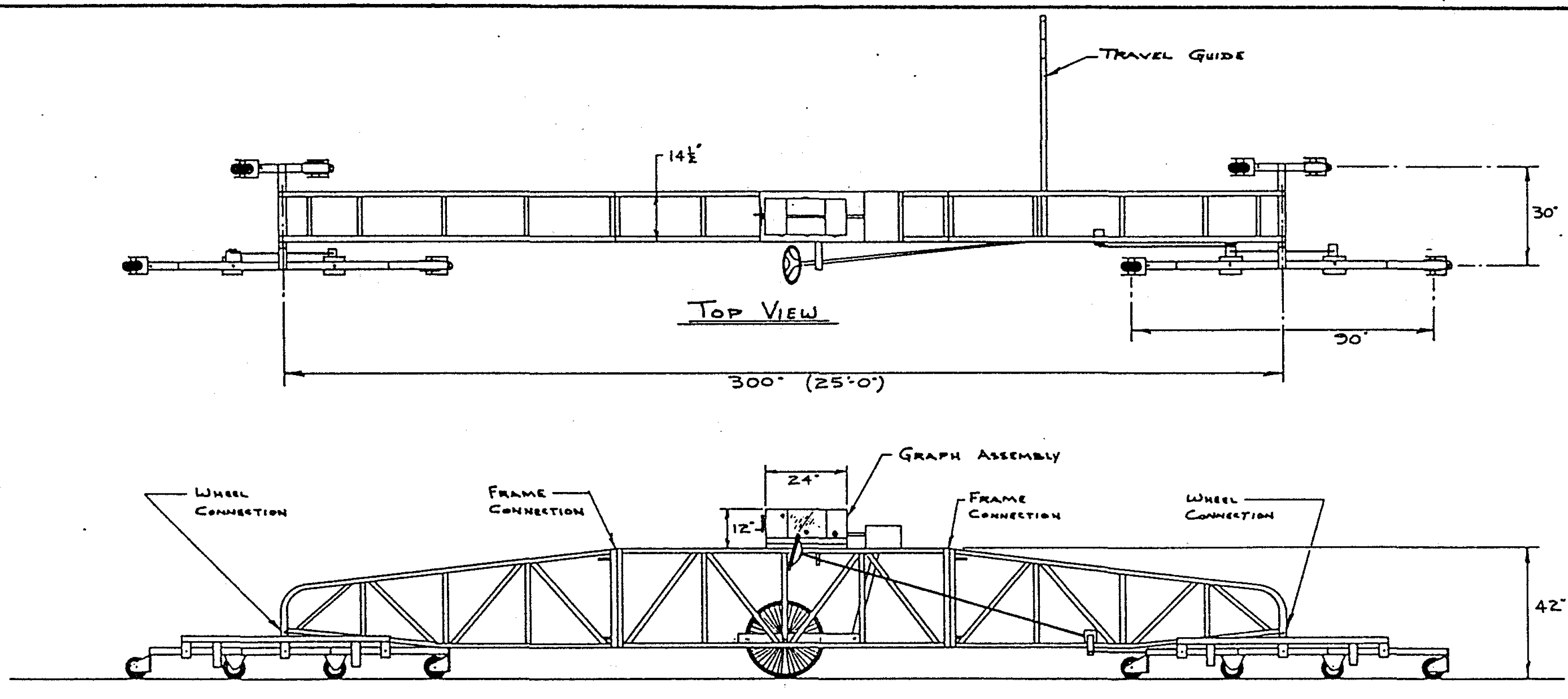
3. Front and Rear Wheel Assemblies

   Both wheel assemblies are equipped with threaded tie rod ends. These can be adjusted for individual caster alignment or unit tracking line up. All the clamps have a threaded spindle which adjusts to maintain a secure grip.

4. Lubrication

   The casters, tandem pivots and tie rod ends should be greased once a month or 100 hours of service. Wipe the dust from the drive chains and apply a light coat of oil. Refer to Step 5, Item #7, for lubrication of the graph recorder. Refer to enclosures for lubrication of the gear boxes.

B-2-10



Side Elevation

Weight: 480#

Disassembled Dimensions: 2'-6" High 5'-0" Wide 8'-6" Long
(For Transport)

Disassembled Pieces: 10

Approx. Assembly Time: 2 men - 10 minutes

Frame and Wheel Connections are Fastened with Lever operated Clamps.

NO.	DESCRIPTION	QTY.	PART NO.	MATERIAL

ISSUE	REVISION	INIT	DATE

TOLERANCE UNLESS OTHERWISE SPECIFIED

	FRACTION	DECIMAL
MACHINING		
FABRICATION		
HOLE LAYOUT		
PATT. NO.		
SCALE None	REF.	

Concrete Pipe Machinery Co.
Sioux City, Iowa

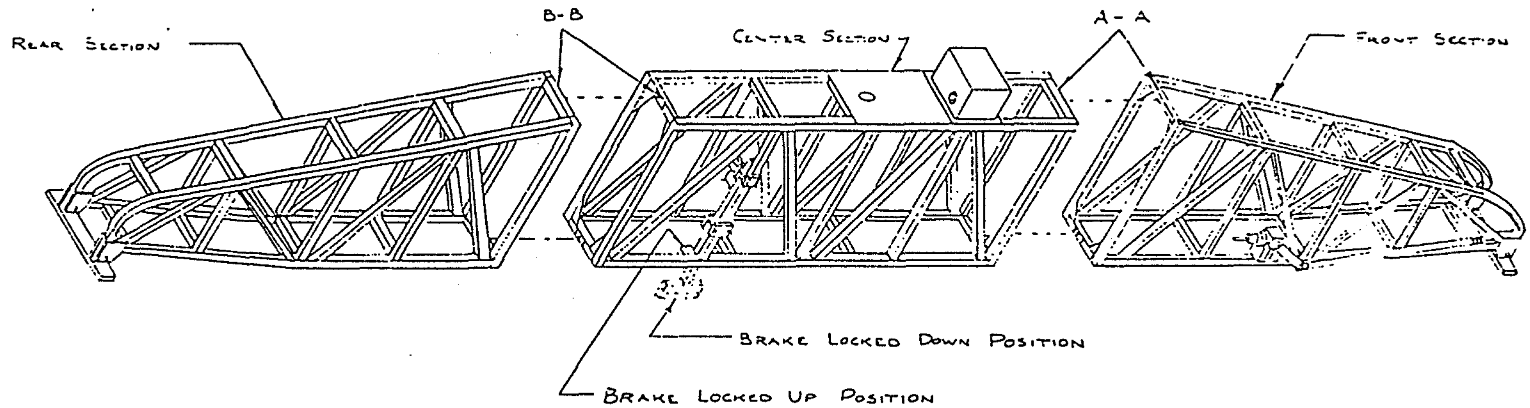
McCracken Profile Reader
General Dimensions

DR.		6-12-84
CHD.		
APP'D.		6/84

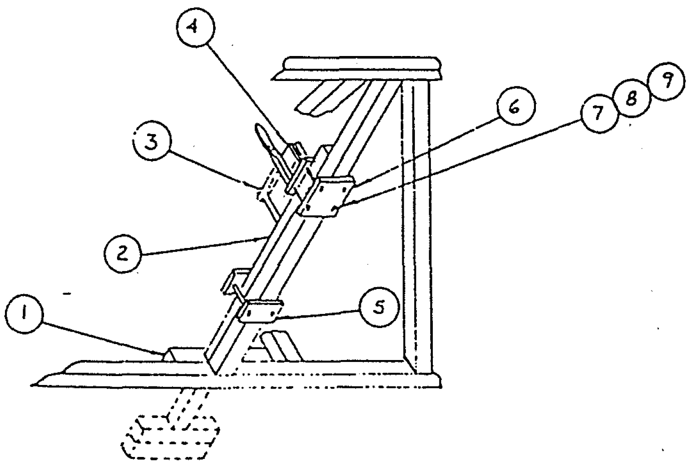
B-N-6725

PROFILE READER ACCESSORIES

1. Parking Brake Assembly
2. Graph Recorder Transport Case



See Detail "A"



Detail "A"

NO.	DESCRIPTION	QTY.	PART NO.	MATERIAL
9	Springlock Washer	6	350457	1/4
8	Hex Nut	6	350356	1/4 - 20 NC
7	Rd Hd Mach. Scr	6	350522	1/4 - 20 NC × 2 1/2 LG (Slotted)
6	Flat	1	A-400146	
5	Flat	2	A-400147	
4	Clamp	1	59746	De-Sta-Co 207-U
3	Socket Hd Cap Scr.	1	350272	5/16 - 18 NC × 2 1/2 LG.
2	Tube	1	A-400148	
1	Brake Weldment	1	B-400149	

ISSUE	REVISION	INIT	DATE

TOLERANCE UNLESS OTHERWISE SPECIFIED

	FRACTION	DECIMAL
MACHINING		
FABRICATION		
HOLE LAYOUT		
PATT. NO.		
SCALE None	REF.	

Concrete Pipe Machinery Co.
Sioux City, Iowa

Profile Reader
Brake Installation

DR.	JB	5-9-85
CHD.	[illegible]	6/13
APP'D.	[illegible]	85

B-N-6846

AMES PROFILOGRAPH
Central Direct Federal Division FHWA

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

The information for the Ames profilograph presented here constitutes an excerpt from a report by Allan S. Miller and Candace E. Watson entitled, "Pavement Rideability Study."

The report focuses on a correlation between the rolling straight-edge and a California-type profilograph.

This excerpt from the above report deals with operating experiences of the Ames profilograph, as well as a list of California-type profilographs, schematic sketches, and samples of comparison roughness traces for the McCracken and Ames profilographs.

Reference: "Pavement Rideability Study"; Central Direct Technical Division, 1987; Allan S. Miller; Candace E. Watson

8. Operation of the Ames Profilograph

The following guidelines are based on observation and experience gained during this study:

a. The profilograph should not be operated in winds exceeding approximately 30 mph. This condition is visible by observing a "harmonic" motion of the box beam.

b. In other winds of significance, tape the lid to the recorder down with duct tape.

c. Use a survey stake for a brake.

d. Do not operate faster than a normal walk. Too fast operation results in excessive bounce chatter on the profilogram which requires more time for interpretation (Figure 13).

FIGURE 13. Trace showing excessive chatter due to too fast operation.

e. The profilograph can be towed if the point of attachment to the towing vehicle is the same height as the front of the profilograph.

f. The rubber feet on the clamps tend to give with time so the clamps should be adjusted periodically (Figure 14).

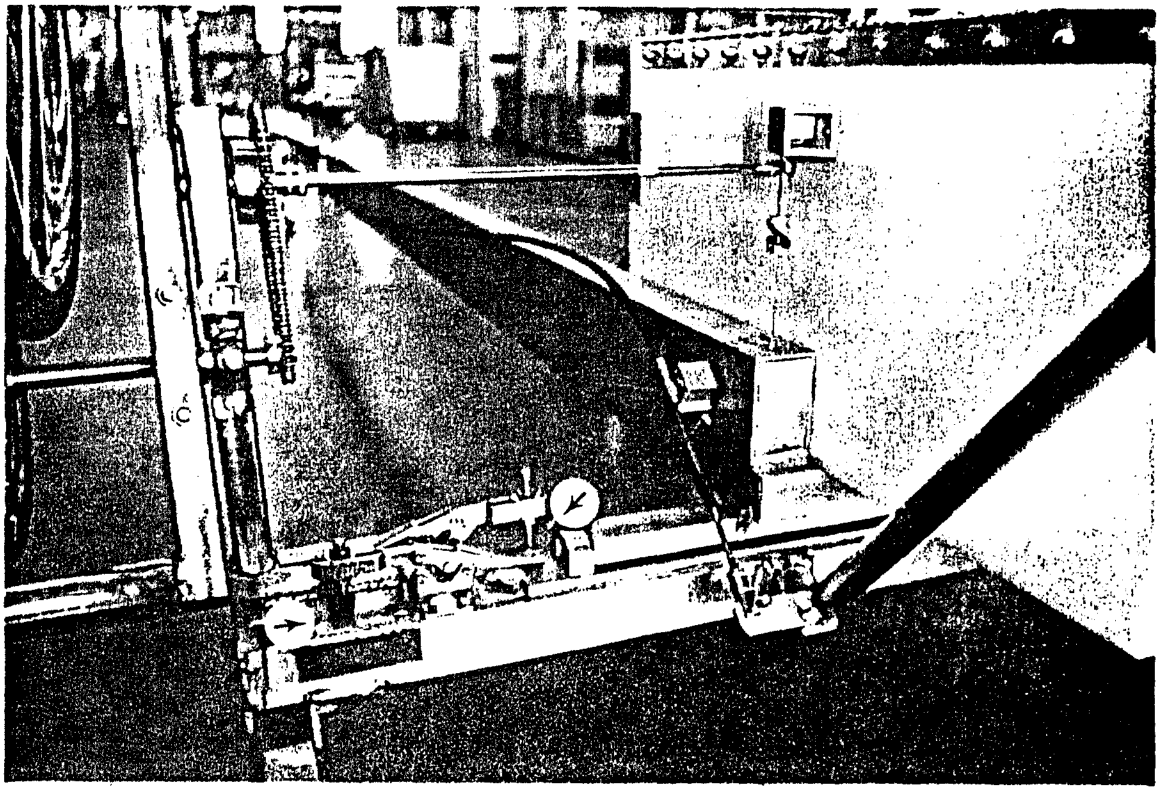


FIGURE 14. Tightness of drive wheel clamps (shown) is especially critical.

g. When going downhill (>3% grade) attach a loose piece of wire or cord between the base of the steering handle and the profilograph. (This will prevent the profilograph from running away if the handle should come loose.)

h. Keep the paper supply centered during operation. (This helps prevent tearing by the pen.)

i. The operator should be particularly observant when the pen crosses the paper folds (perforations). The pen may get caught and tear the paper.

j. Attach a piece of string to the front cotter pin. (Attach loosely to cable or frame.) This prevents loss or extensive searching if the cotter pin falls out.

k. When operating along supers greater than 0.03, have someone to keep the front from pulling off line.

l. Box beam sections should be stored and transported flat and fully supported to prevent warping (Figure 15).

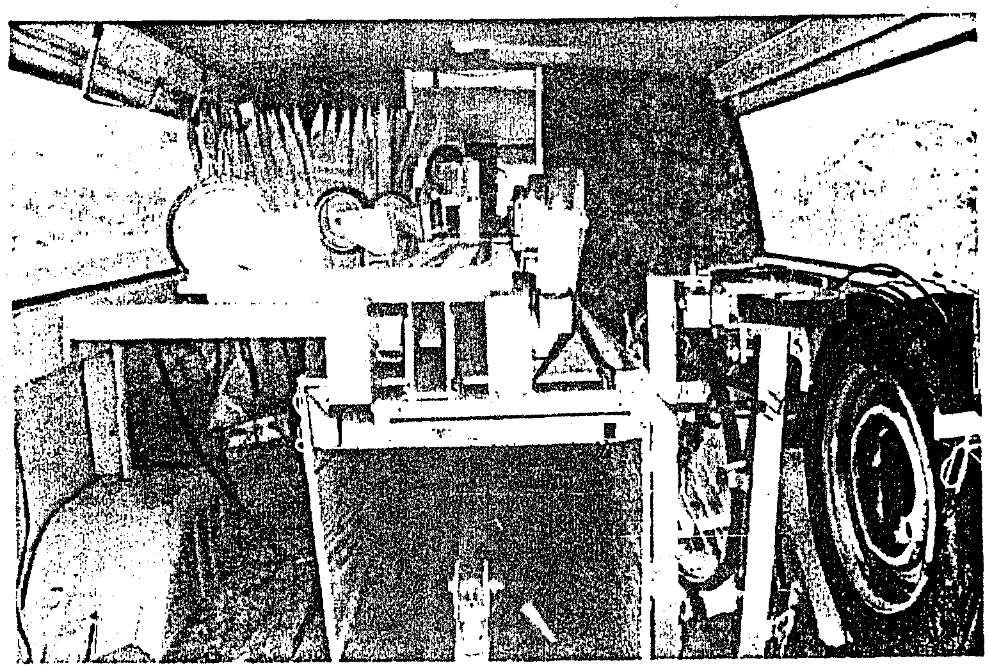


FIGURE 15. Profilograph loaded for transport. (Note beam sections supported on box.)

m. Avoid too rough areas such as cattleguards, etc.

n. Cover the rear with a tarp and head for vehicle if rain or lightning threaten.

o. Check tire pressure of drive wheel before each run (29-31 psi).

p. Check tightness of drive wheel chain before each run.

q. Do not leave recorder box exposed to sunlight for long periods. (Ultraviolet rays deteriorate the plastic.)

r. All components get very hot in the sun - wear gloves. (Heat does not affect the readings.)

s. When leaving the profilograph set up (overnight, etc.), provide lateral support to the center (measuring) wheel in case high winds develop.

t. Because of the low profile of the machine, a red flag was attached to the front to provide a measure of safety in traffic (Figure 16)

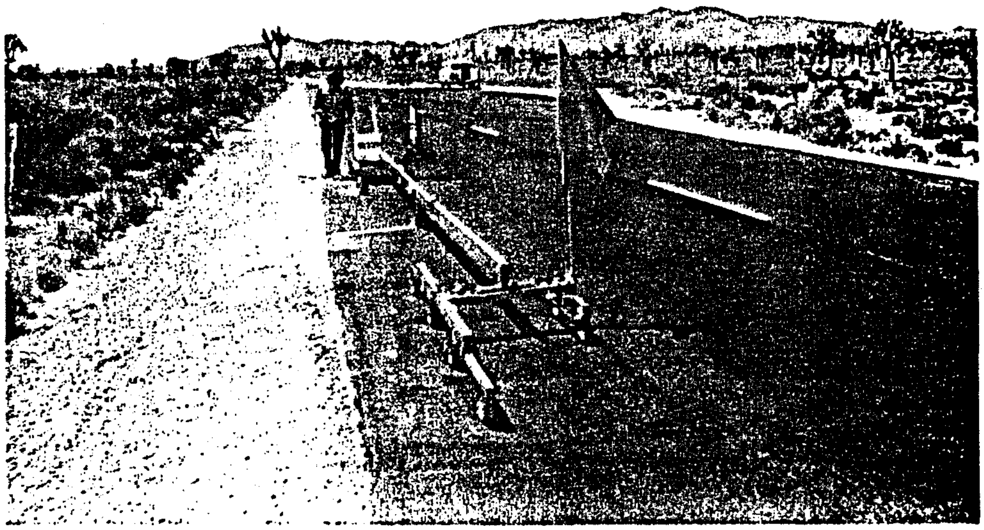


FIGURE 16. Profilograph on Route 12, Joshua Tree N.M.

9. Conclusions and Recommendations

a. The results of this study show that the profilograph and specifications based on the profilograph data could and should be applied to most AC pavement constructed by CDFD.

b. The Ames Profilograph is the best available for use by CDFD.

c. The investment is warranted since the nationwide trend is toward:

(1) More states with rideability specifications and

(2) The increasing dominance of the profilograph for quality control (Figure 17).

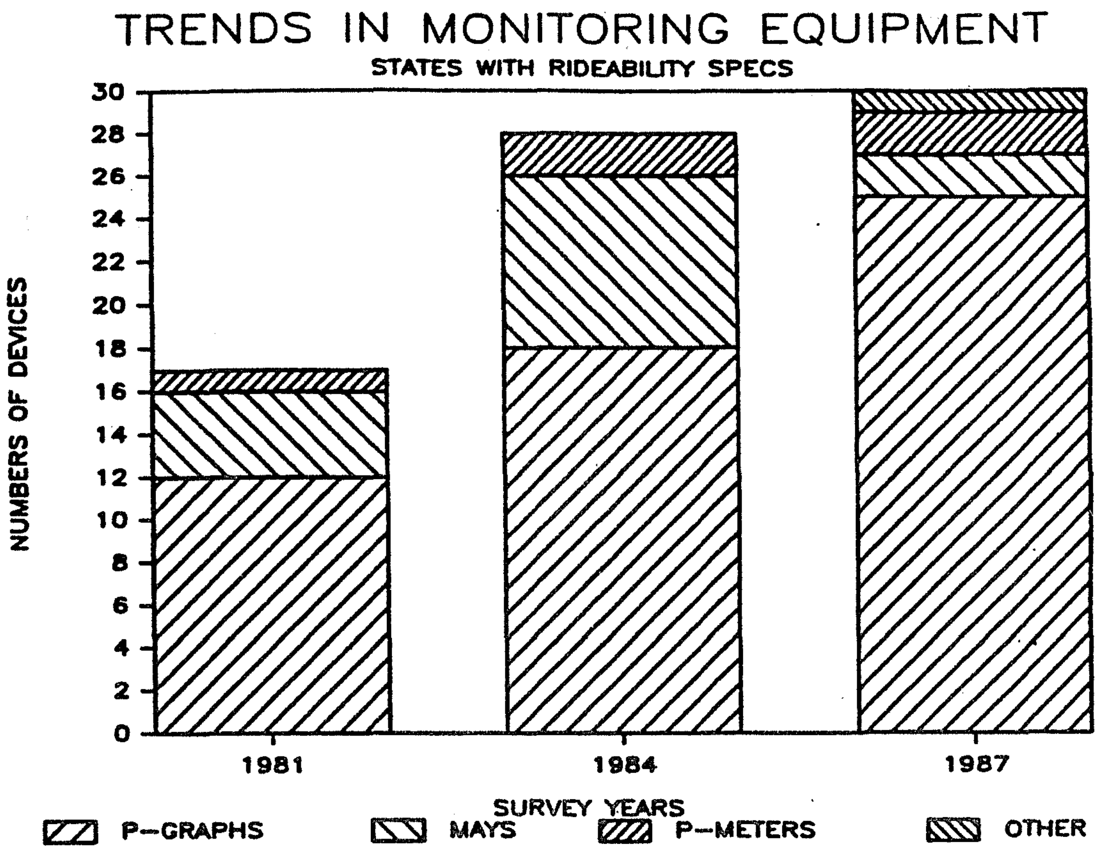


FIGURE 17. Trends from AASHTO 1987 survey of the states.

d. The main factors noted in this study which affect smoothness on new construction are as follows:

   (1) Alignment - very sensitive,

   (2) Grade - not sensitive on tangents, and

   (3) Turnout approaches and turn lanes - always rougher to some degree.

e. Recommendations - The following are preliminary recommendations based on this study:

   (1) Curves greater than 16° (R≈350') to be exempt from the specification,

   (2) Test mainline lanes only,

   (3) Only one run per lane is necessary,

(4) Specifications be "tailor-made" for each project. An example of this is the type of construction (e.g., layered versus full depth). It is well known that successive layers are smoother so on full-depth construction blue top grade control becomes more critical.

(5) A continuing roughness monitoring program be initiated on newly constructed roads. This would provide valuable information for future designs and specifications.

(6) Personnel responsible for monitoring roughness be trained and experienced in operating equipment and reducing profilograph traces.

TABLE 1. Manufacturers of California-Type Profilographs

Manufacturer	Cost	Availability
McCracken Concrete Pipe Machinery Co. P.O. Box 1708 Sioux City, IA 51102 (712) 277-8111 Corey Noonan	$12,400 (Options- $955.00)	3-4 weeks
MacBeth Engineering Corp. P.O. Box 1469 Tenth & Hanna Streets Harrisburg, PA 17105 (717) 234-3069 Mary Ann Fischer	$12,950	8-12 weeks
Ames Profilograph 200 Rockwell Avenue Ames, IA 50010 (515) 292-8194 Dick Angove	$6,400	4-6 weeks
Thompson-Quill Assoc. 12445 East 39th, Suite 210 Denver, CO 80239 (303) 373-8595 Steve Thompson (Soiltest)	$19,400	8 weeks if not in stock

The Ames Profilograph has been recently developed. The mechanics used to generate the trace are different from the "standard" California type profilograph. This difference is shown schematically in Figure 2.

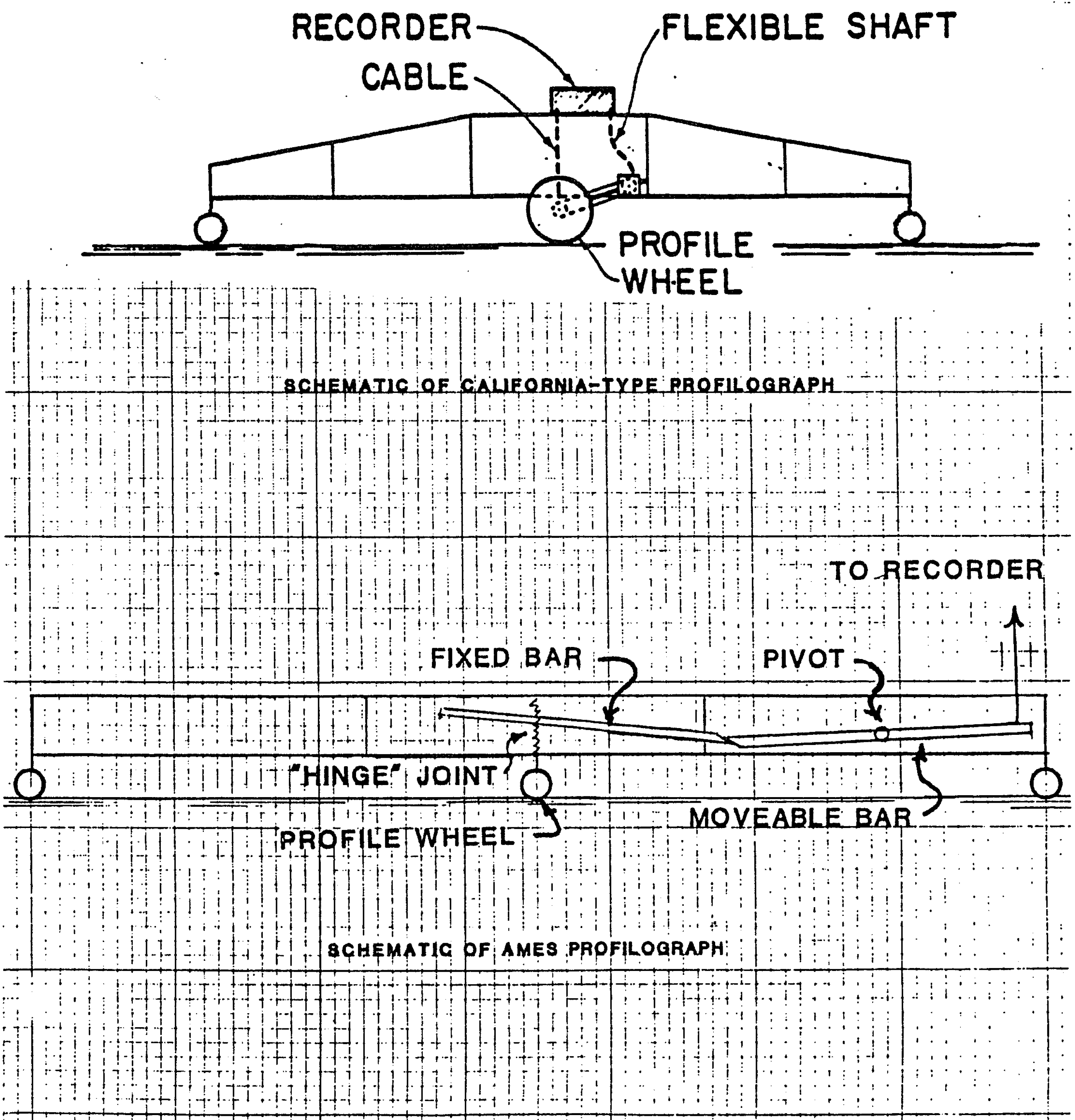


FIGURE 2. SCHEMATIC SKETCHES OF PROFILOGRAPHS

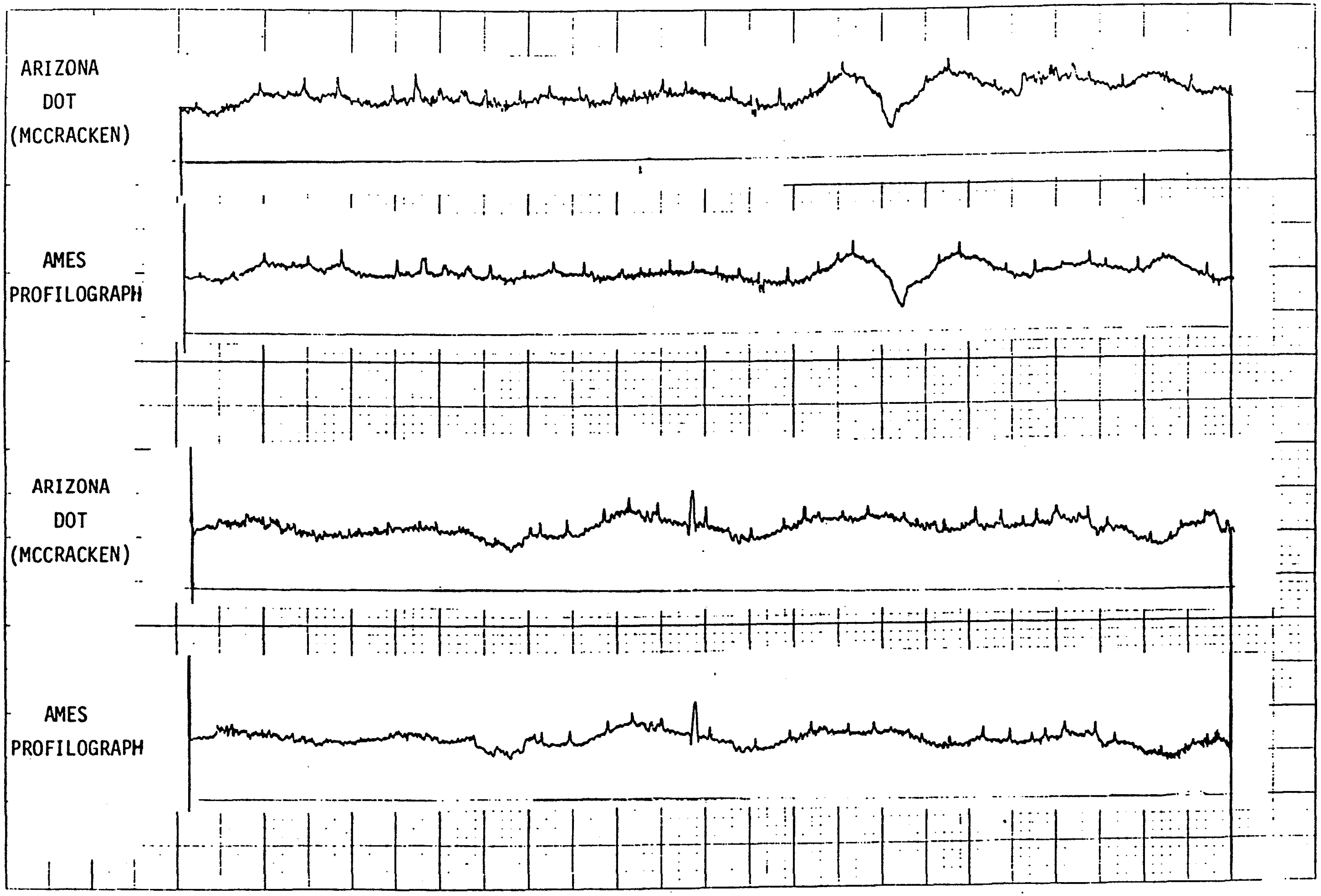


FIGURE 5. - COMPARISON TRACES

DIPSTICK
E. W. FACE COMPANY

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

THE E. W. FACE DIPSTICK ROAD PROFILER

(Precision, high-speed, auto-recording, rod-and-level replacement system)

The E. W. Face Dipstick* measures "true" road profiles at a pace and precision heretofore unattainable - and at only a fraction of the cost associated with conventional rod-and-level surveys. In just one hour, this "one-man rod-and-level crew" can automatically record and analyze up to 900 equally-spaced, co-linear elevation points to an accuracy of 0.0015 inch/reading.

Dipstick data collection and processing activities are all completely automated. In operation, the individual Dipstick readings are fed directly into an 18K microcomputer/printer which then calculates and prints-out in the field all of the required profile statistics (IRI , FF-number , elevation and curvature values, etc.) - as well as a continuous plot of the measured surface. The recorded readings may also be relayed back (using the kit's phone modem) to an office PC for formal report generation and disk storage. The 18K microcomputer software supports a user-allocatable file system that can store in aggregate up to 6000 Dipstick readings. Should the microcomputer's file capacity ever be exceeded, the file contents may be dumped to tape (in about 15 minutes) using the mini-cassette recorder supplied with the Dipstick kit.

The Dipstick Road Profiler is a fully integrated data collection and processing system. The suitcase-size kit includes all of the hardware and software elements necessary to marry field and office operations. The Dipstick's speed, simplicity, extraordinary accuracy, and state-of-the art data processing capabilities far surpass anything attainable with conventional rod-and-level survey techniques.

PRINCIPAL USES:

The true pavement profiles generated by the Dipstick have two principal applications:

- the calibration of high-speed road meters,
- & tolerance control on projects having limited daily production (bridge decks, streets, runways, etc.)

The unit's unique profiling and computer analysis capabilities allow it to be used efficiently for both these surveying tasks. Since the Dipstick automatically records the road profile in digital form, the device can be used to evaluate the profile against any form of riding index or dimensional tolerance. At the user's option, for example, the present software computes the profile's International Roughness Index (IRI), its FF-number local curvature statistic (per ASTM E-1155), its relative compliance to any user specified straightedge tolerance, and its relative compliance to any user specified California profilograph tolerance. The Dipstick microcomputer/printer will also generate both a true profile plot of the surface and a simulated California profilograph tape for immediate visual reference.

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* The "DIP" in Dipstick stands for Digital Incremental Profiler

THE NEED FOR CALIBRATING HIGH-SPEED ROAD METERS:

Since their measurements are all influenced by chassis components or on-board instruments which invariably change over time, all high-speed road roughness meters (both response and profilometer type) are necessarily unstable devices. There is general agreement that the errors which result from this instability must be minimized both through strict adherence to standardized survey procedures (e.g. the use of cruise control, maintenance of uniform tire pressures and shock types, limits on wind speed, etc.) and through periodic calibration against a time-contant reference. (The situation is exactly analogous to the regular recalibration required for weigh scales.)

All road agencies using roughness meters as part of their pavement management operations must regularly calibrate their meters at normal operating speeds on pavements of known roughness. Some state highway departments have already established road meter calibration circuits for this purpose. These circuits are comprised typically of 10 to 40 designated road sections, each 1/5 to 1/2 mile long, covering a wide spectrum of roughnesses. In the past, calibrations have been made either to a jury rating panel, or to a CHLOE Profilometer, or to a designated "standard" road meter selected from the vehicle fleet. While better than no calibration at all, none of these procedures uses a truly time-constant reference, so none is capable of insuring the long-term integrity of the road inventory data required for reliable condition comparisons.

The intent of calibration is to generate, for each individual road meter/host car combination, a calibration curve unique to that combination which relates data output (e.g. counts per mile) to a standard reference scale. These calibration curves are then applied to all subsequent network inventory readings made by the calibrated road meter. This permits reliable comparison of all data generated by similarly calibrated devices. (The calibration procedure also identifies mechanical deficiencies in the host vehicles which will adversely affect the consistency of the roughness ratings.)

IRI - A TIME-CONSTANT CALIBRATION STANDARD:

The International Roughness Index (IRI) was developed several years ago by the World Bank specifically to provide the type of time-constant, universal reference required for effective roughness meter calibration. The determination of a road's IRI value is entirely objective: it is based solely on the response of a <u>mathematical</u> quarter-car model to the "true" road profile. A standard wheel/spring/shock absorber/mass assembly (the quarter-car) is modeled by a differential equation which uses the road profile (as depicted by a series of equally-spaced point elevations) as the forcing function input. The cumulative severity of the quarter car's response to the profile is summarized by the IRI statistic.

Since the IRI does constitute a portable, non-subjective, non-device dependent gage of riding quality applicable to all categories of road surface, it has now been adopted by the Federal Highway Administration (FHWA) as the standard index to be used for reporting ride quality to the Highway Pavement Management System (HPMS). The IRI (inch/mile) thus replaces the Present Serviceability Index (PSI), Riding Comfort Index (RCI), ARV , RMSVA , and the various locally-derived "sum-of-the-counts" ratings as a universal standard for reporting pavement riding comfort in the United States.

DIPSTICK SURVEYS OF IRI CALIBRATION CIRCUITS:

Detailed instructions for the establishment of a road meter calibration circuit are described in World Bank Technical Paper Number 46.*

Where roughness meters are primarily intended for use on paved roads, FHWA is requiring at least a Class 2 IRI survey procedure (modified to reduce the reading point spacing to 1 foot) for rating the calibration circuit profiles. A Class 2 survey requires that profile elevations be measured to an accuracy of 0.04 inches. An IRI Class 1 survey requires a reading accuracy of 0.02 inches over the same 12-inch interval. With an accuracy of better than 0.002" per reading, the Dipstick is at least an order of magnitude more accurate than the minimum required for any of the IRI calibration levels.

As noted above, the Dipstick provides an extremely fast and convenient method for surveying wheeltrack profiles to much better than either Class 1 or Class 2 standards. The auto-read feature - coupled with the pre-programmed microcomputer/printer - permits calculation of calibration section IRIs as soon as the survey is completed.

The Dipstick/microcomputer combination sits atop two pins spaced exactly 12" apart. When the unit is stood upright on the pavement, it measures, displays, and captures in memory the elevation difference between the two pin feet. By "walking" the Dipstick in swivel fashion down the survey line, the technician automatically measures and records the sequential elevation differences between a series of points spaced at constant 12-inch intervals. This series of elevation differences is fundamental to the calculation of IRI .

The advantages of the Dipstick over rod-and-level methods for this application are obvious:

- The measurement precision, at +- 0.0015 inches/reading, far exceeds the accuracy to be achieved with any optical or laser level.

- The preset 12-inch point spacing eliminates the requirement for laying-out and marking survey points in the field.

- In terms of total manhours expended, Dipstick measurement and data processing procedures are at least 20 times faster than conventional rod-and-level survey techniques. A single technician can automatically measure, calculate, and report IRI at the rate of 900 ft/hr - with the computer retaining all data for subsequent transfer to office PC or magnetic tape.

- By summing the Dipstick readings, the microcomputer also calculates the elevation of each point relative to the start point, and with this information, plots the true profile, corrected for any cumulative error, to any desired vertical scale.

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* Guidelines for Conducting and Calibrating Road Roughness Measurements; Sayers, M.; Gillespie, T.; Paterson, Wm.; 1986; World Bank Technical Paper Number 46; The World Bank, 1818 H St. NW., Washington, D.C. 20433.

PROFILE FLATNESS ANALYSIS BY THE DIPSTICK:

The Dipstick has been used for years in the concrete flooring industry for the evaluation of finished floor flatness and levelness relative to contract specifications. The Face Floor Profile Numbering System (the "F-number" System) - now formalized in ASTM E-1155 - has been adopted by the American Concrete Institute (ACI) as the industry standard for specifying floor tolerances (see ACI-117 & ACI-302). In fact, much of this floor quality control technology has direct application to road construction. The Face Floor Flatness Number (the "FF-number"), for example, when combined with the true profile plot, has already found significant use in the specification and control of bridge deck profiles. The speed, accuracy, and convenience of the Dipstick, coupled with the sophistication of the F-number System, provide a quality control scheme far superior to that available with rolling straight-edges or profileographs on projects involving installation rates of up to 5000 sqyd/day.

DIPSTICK ROAD PROFILER KIT SPECIFICATIONS:

The complete Dipstick Road Profiler kit is packed in a 22" x 7" foam-fitted Zero aluminum instrument case (total weight = 30 lbs.) The kit includes the following items:

- Dipstick Road Profiler (auto-record model w/ "hiway" swivel pad feet)
- Sharp PC-1500 18K Portable Microcomputer
- Sharp CE-150 4-Color Graphic Printer/Cassette Interface
- Sharp CE-152 Cassette Tape Recorder
- Sharp CE-158 RS-232C and parallel interface
- Migent Model MM1200 Pocket Modem
- GE Model 3-5340A Microcassette Audio Tape Recorder (for optional oral data recording & note taking)
- Complete Dipstick Software Library (includes all programming necessary for PC-1500 microcomputer to IBM PC compatible interfacing, Dipstick data processing/storage, and report & graph generation on both machines)
- All associated cords, cables, accessories and instruction manuals

The Dipstick Road Profiler is available from:

The Edward W. Face Company, Inc.
427 West 35th Street
P.O. Box 6300
Norfolk, Virginia 23508
(804)-624-2121

Dipstick Surveys For IRI Calibration

INTERNATIONAL ROUGHNESS INDEX - IRI

The International Roughness Index, IRI, is the universal standard for quantifying pavement roughness and riding comfort in a vehicle at speed. Developed by the World Bank, and adopted by the Federal Highway Administration, the IRI provides a valid, rational index of riding quality over any roadway surface.

The IRI statistic for a given road profile is derived from the simulated dynamic response of a mathematical model "quarter car" run at a constant speed over a series of closely spaced sequential profile points. A standard tire/spring/shock absorber assembly (the "quarter-car") is modeled in the computer which uses the measured road profile as the forcing function input. The cumulative severity of the quarter car's response to the profile is then summarized by the IRI statistic.

The IRI rating provides a universal time-stable standard to which all high-speed road meters of whatever design can be readily and repeatedly calibrated. Network inventory and pavement management reports will reference a universal roughness rating statistic, expressed as inches per mile.

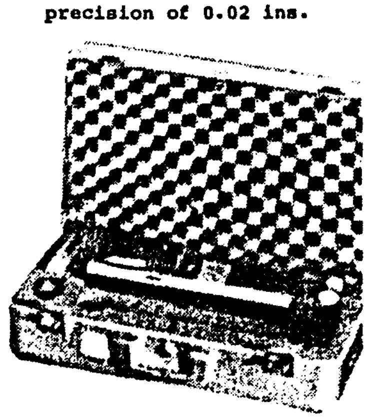
Road roughness meters of all types require calibration at least annually. This is done by comparison to roads of known IRI roughness. Precision wheelpath profiling assures accurate IRI determination for each segment of such a calibration circuit.

The Face Dipstick -- Digital Incremental Profiler = DIP -- provides the means to complete these precision profile measurements at a pace and accuracy far greater than traditional rod and level survey procedures. Related software, either off or on-site, calculates the IRI for each wheelpath surveyed by the Dipstick.

FIELD SURVEY OF IRI

An IRI survey may involve the collection of profile readings in one or both wheelpaths. Readings may be taken at intervals from 1 to 2-ft, depending on the class of profile survey performed. The required elevation reading accuracy is between 0.020 ins. and 0.240 ins., again depending on the survey class.

Class 1 IRI surveys (the highest class) are required for calibration of road meters intended to run on high-quality paved surfaces. Class 1 calibration involves the measurement of some 12 to 20 wheelpath calibration strips from 1/8 to 5/8 mile long. Each strip is surveyed in the wheelpath at intervals of 1.0 ft. to an elevation precision of 0.02 ins.



DIPSTICK SURVEYS OF IRI

The Dipstick Profiler stands on its two pins spaced at 1.00 ft. Two digital displays are provided - one at each end of the instrument. Each LCD displays the elevation difference in thousandths of an inch between its pin relative to the other pin when positioned on the road surface. The displayed readings are accurate to within +- 0.002 ins.

To make a Class 1 IRI calibration survey, the operator simply "walks" the Dipstick down the pre-marked wheelpath by alternately pivoting the instrument about each leg. The auto-read capability of the Dipstick records sequentially the difference in elevation between equidistant points along the survey line. The Dipstick itself pre-determines the constant 1.00 ft. interval, making interval markings in the wheelpath unnecessary.

A signal light alerts the operator when the Dipstick computer has captured the reading (about 4-seconds per reading) and then the Dipstick is pivoted to the next point. A single operator can measure, record and calculate IRI for a typical 1/5 mile calibration strip in less than 2 hrs.

Alternatively, the Dipstick LCD readings may be recorded orally on the tape recorder provided or manually entered on the portable PC-2 computer/printer which forms part of the kit. For each wheelpath surveyed, the data recorded may be processed either on-site directly by the 18K PC-2 or transmitted by modem as ASCII data to a larger CPU to calculate each section's IRI.

The PC-2 computer/printer included with the Dipstick can serve both as the automatic data recorder and IRI computer, as well as the processor of manually-entered survey data. The preprogrammed PC-2 immediately performs all of the required calculations and prints a hard copy of the selected results on a 2.5 ins. wide paper tape. The operator may also save data from the PC-2 onto magnetic tape for later analysis.

Dipstick®

THE EDWARD W. FACE COMPANY
DIPSTICK DIVISION
P.O. Box 6341 • Norfolk, VA 23508

THE DIPSTICK IRI PRINT OUT

A sample of the optional IRI profile analyses available from the Dipstick computer appears at right. For every measurement point down the survey line the printout lists the following information.

- Point Number
- Distance from start-point, feet.
- IRI to that point, in./mile
- Point to point elevation difference, ins.
- Local 3-point curvature, ins.
- Point elevation, ins., relative to the mean elevation

For the point-point difference, 3-point curvature, and point elevation data, the following summary statistics are also listed:

- Highest positive value and location
- Lowest negative value and location
- Average value
- Standard Deviation

The printout also reports the following overall profile statistics:

- Overall IRI, inches/mile
- F-Number for Flatness, F_F

Finally, if instructed, the computer will plot the profile to scale.

Dipstick®

The complete kit, packed in a foam fitted aluminum Zero instrument case (22x14x7 ins.), is available from

The Edward W. Face Company, Inc.
427 West 35th Street
P. O. Box 6341
Norfolk, Virginia, U.S.A. 23508
Phone: (804) 624-2121
Fax: (804) 624-2128
Telex: (510) 600-1039

SAMPLE COMPUTER

PRINTOUT

FAST, PRECISE, COMPLETE

Dipstick data collection and processing is extremely fast. The auto-record feature permits data acquisition at better than 800 readings an hour, with near-instant IRI calculation at the end of each survey run. Full data presentation requires proportionately longer time to print. Complete survey of both wheelpaths of two 1056 ft. (1/5 mile) IRI calibration sites can be measured by a single operator in a day.

The Dipstick-IRI Survey kit consists of the following items:

* Dipstick Profiler with auto-read port
* Portable TRS-80 PC-2 18K computer/printer which serves as data recorder
* Dipstick IRI analysis software
* Microcassette audio tape recorder
* Minicassette data tape recorder
* Modem and RS 232 serial port
* All related accessories and manuals

: DEMO RUN

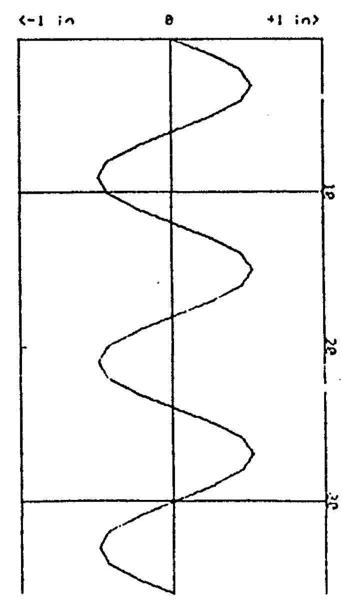
Test #: 1234ABCD

Pt 0 Elev = 0.00 in
Pt 36 Elev = 0.00 in
Operator Bias = 0.0000 in/rds

Pt #	IRI in/mi	Pt-Pt Dif	Local Crv	Pt Elev
0	##.##	#.###	#.###	0.00
1	411.08	0.250	#.###	0.25
2	702.70	0.183	-0.067	0.43
3	797.41	0.067	-0.116	0.50
4	657.98	-0.067	-0.134	0.43
5	695.20	-0.183	-0.116	0.25
6	861.43	-0.250	-0.067	0.00
7	1013.18	-0.250	0.000	-0.25
8	1072.38	-0.183	0.067	-0.43
9	1019.66	-0.067	0.116	-0.50
10	959.43	0.067	0.134	-0.43
11	986.75	0.183	0.116	-0.25
12	1048.59	0.250	0.067	0.00
13	1101.62	0.250	0.000	0.25
14	1116.43	0.183	-0.067	0.43
15	1079.19	0.067	-0.116	0.50
16	1032.18	-0.067	-0.134	0.43
17	1037.40	-0.183	-0.116	0.25
18	1069.52	-0.250	-0.067	0.00
19	1101.45	-0.250	0.000	-0.25
20	1110.40	-0.183	0.067	-0.43
21	1082.84	-0.067	0.116	-0.50
22	1050.45	0.067	0.134	-0.43
23	1056.15	0.183	0.116	-0.25
24	1082.25	0.250	0.067	0.00
25	1108.48	0.250	0.000	0.25
26	1117.12	0.183	-0.067	0.43
27	1097.08	0.067	-0.116	0.50
28	1069.67	-0.067	-0.134	0.43
29	1072.15	-0.183	-0.116	0.25
30	1091.21	-0.250	-0.067	0.00
31	1110.90	-0.250	0.000	-0.25
32	1116.83	-0.183	0.067	-0.43
33	1099.62	-0.067	0.116	-0.50
34	1077.64	0.067	0.134	-0.43
35	1080.00	0.183	0.116	-0.25
36	1096.08	0.250	0.067	0.00
# READINGS:		36	35	37
HI + READNG:		0.250	0.134	0.500
HI + LOCATN:		1	10	3
LO - READNG:		-0.250	-0.134	-0.500
LO - LOCATN:		6	4	9
AVERAGE RDG:		0.000	0.000	0.000
STANDRD DEV:		0.1856	0.0974	0.3535

F(F) NUMBER: 15.6 < 18.9 - 12.4>

IRI (in/mi):1096.1



MAYS RIDE METER (CAR-BASED)
WYOMING HIGHWAY DEPARTMENT

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

PAVEMENT PROFILE MEASUREMENT SEMINAR
FHWA DEMONSTRATION PROJECT NO. 72
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

Mays Ride Meter: Calibration, Operation and Costs

BY: MIKE FARRAR, P.E.
Materials Engineer, Wyoming Highway Department

INTRODUCTION

The Mays Ride Meter (MRM) is a relatively inexpensive, durable, easy to operate device for measuring highway surface roughness. The MRM has been in use by a number of Federal, State, and private entities for many years. The Wyoming Highway Department has used the MRM for the last 10 years, primarily to inventory the State Highway System for surface roughness.

The MRM is well documented in the literature and therefore, this report for the PPM Seminar will concentrate solely on Wyoming's experience with the MRM in regard to equipment configuration, calibration, operation, and costs.

COMPONENTS

The MRM is mounted in a 1986 Chevrolet Caprice and consists of the following equipment:

1. Odometer
2. Rotary Transmitter
3. Pavement Condition Recorder (PCR)
4. Data Playback Unit (DPU)

The Rotary transmitter is manufactured by Rainhart Co., Austin, Texas. The PCR and DPU are new items that have replaced the traditional strip chart recorder provided by Rainhart. The PCR and DPU can be purchased from International Cybernetics Corporation (ICC) Largo, Florida.

The Rotary Transmitter is essentially a transducer that converts the vertical axle/body movement to an electrical signal. The transmitter, permanently mounted in the trunk, has a 4 track mylar film program mounted in its direct drive, axle attached shuttle; this program is read by tiny (1/16 inch diameter) photo cells converting the mechanical motion to an electrical signal.

The PCR is a self contained pavement condition recorder designed to operate on a 12 volt DC system. Principal features include a 28 key front panel keyboard, digital display, 20 column thermal printer and microcassette tape capability. The PCR records the individual axle/body excursions and accumulates the total roughness in the test run. Each 1/10 inch of relative motion results in one count recorded by the PCR.

The DPU is used along with a communications program developed by ICC to transfer data stored on microcassette tape to an IBM-XT. The data is then cleaned of extraneous characters and transferred to a mainframe computer via a phone link using FOCTALK (release 2.0) a communication program purchased from Information Builders, Inc., New York, N.Y. Final processing of the data is completed on the mainframe.

Output is measured "count" based on the relative axle/body motion: Sixty four counts is equal to one inch of chart roughness as measured by Rainhart's strip chart recorder.

Inches Chart Roughness/Mi = Total Count/(Net length * 64)

Figure 1 is an example of the output from the PCR, which, in addition to storing the data on microcassette tape also produces and optional hard copy during testing. The output shown is somewhat cryptic and an explanation of the various headings is provided in the margin.

As shown in Figure 1 the roughness count was measured in increments of 0.05 miles which is the smallest increment the PCR is capable of measuring. Normally for large scale inventory testing an increment of 0.5 miles is used. Typically two to three microcassette tapes are required per day when conducting inventory testing. Each cassette tape hold approximately 50,000 bytes of data.

Data processing consists of converting the measured "count" to a Present Serviceability Index(PSI) and massaging the data into report form using a data base program on the mainframe computer. The conversion of "count" to PSI is based on a Present Serviceability Rating (PSR) study conducted by the WHD in 1981.

OPERATION

Testing is performed at 50 mph. Normally when conducting inventory testing 200-300 miles per day can be covered. In Wyoming there are approximately 6000 miles of highway in our system and it takes 1-1 1/2 months to complete.

Typical Mays Ride Meter Output

```
                 TOTAL COUNT          423.
                 [2] MAYS RATING
                 DATE               080585
                 TIME                 1000
                 INDEX #              0000
                 TEMPERATURE            85
                 SPEED                  50
                 COMMENTS                8
                 BEGIN M.P.          10.75
                 DIRECTION               8
                 LANE                    2
                 SELECT DCF             01
                 RECORD MODE             3
                 OP/VEH/MAYS           111
                 DIST. INCR.          .050
                 DCF:1              .16500
                 CONSTANT:1              1
                 COEF.:1                 1
                 [7]M.P.     NET       CNT      Distance increment in miles
Begin testing    B 10.649  00000053
                 I 10.599  0.050        23      Count
Hold             H 10.591  0.008         4
Bridge           I 10.549  0.000         0
                 C 10.540  00000981
Continue         I 10.499  0.041        31
                 I 10.449  0.050        35
                 I 10.399  0.049        26
                 H 10.366  0.033        29
Bridge           I 10.349  0.000         0
                 C 10.329  00002517
                 I 10.299  0.029        16
                 I 10.249  0.049        45
                 I 10.199  0.049        39
Increment        I 10.149  0.049        20
                 I 10.099  0.049        29
                 I 10.049  0.049        18
                 I  9.999  0.050        21
                 I  9.949  0.049        27
                 I  9.899  0.049        27
                 I  9.849  0.050        14
                 E  9.802  0.047        19
End Testing      NET LENGTH          0.759
                 ELAPSE TIME      00005336
                 TOTAL COUNT          423.
                                                Total Count
```

Figure I

$$\frac{\text{Avg. Roughness}}{\text{Mile}} = \frac{\text{Total Count}}{64 * \text{Net length}}$$

$$= \frac{423}{64 * .759} = 8.7/\text{Mile}$$

Two employees are required for testing: one to operate the PCR and the other to drive. The operator enters initial record keeping data into the PCR, verifies that the data is correct and is ready to begin. During operation the PCR is placed on hold for, bridges and cattleguards by the operator. Qperation of the PCR is relatively simple and can be mastered with only several days training.

Testing is not recommended below 60° or above 90° degrees Fahrenheit. We have not performed a formal study but it appears the MRM is sensitive to temperature by as much as 1 inch of chart roughness per 10 degrees. The temperature is recorded during testing to allow for a temperature correction factor to be applied latter.

Also the gas tank is kept above the 1/2 tank level to help minimize fluctuations in vehicle response due to an increase or decrease in weight.

CALIBRATION AND PAVEMENT MANAGEMENT

The WHD is currently developing a comprehensive Pavement Management Program (PMP). We are particulary interested in developing pavement performance curves which require an accurate historical record (10-15 years) of highway surface condition. We consider roughness the principal determinant of surface condition and it is therefore essential that the MRM data be calibrated on a long term basis allowing the evaluation of roughness collected over many years.

Unfortunaly as with any response type road roughness measuring (RTRRM) system the MRM is highly susceptible to variation in the vehicle suspension, weight distribution, speed, etc. Accurate long term calibration of the MRM is difficult to achieve.

Our current calibration of the MRM consists of:

A. Periodic control checks to assure the MRM recorder, transmitter and vehicle are operating in a consistent manner.

B. An annual calibration of the current year's MRM data to the previous year.

Both the periodic control checks and the annual calibration of the MRM are based on approximately 20 control sections located throughout the State. Each control section is 1/2 mile in length and located on a relatively straight and level section of highway that has a low ADT. We require low ADT because we make the assumption that our control sections do not significantly increase in roughness over a one year period. This assumption is probably valid for calibration of data over a period of 3-5 years but beyond 5 years a significant error tends to creep into the analysis. What we are looking for is reference standard to calibrate the MRM against.

We are currently evaluating a profilograph as a reference standard. Preliminary results indicate a correlation coefficient of 0.94 which is better than anticipated considering the limitations of profilographs in measuring certain wave lengths and difficulties encountered in interpreting the profilograph traces.

We are also considering using a profilometer as a reference standard although until recently the high cost of profilometers tended to eliminate this as a viable alternative.

Finally, since the price of profilometers is dropping and the equipment now appears to be beyond the prototype stage we are giving serious consideration to eliminating entirely the MRM calibration "headache" by purchasing a high speed profilometer to use for all our roughness testing.

MRM OPERATING COSTS

Two employees cost roughly $250-$350 per day including per diem. The only other operating costs are incidental such as fuel for the vehicle, thermal printing paper, and microcassette tapes.

MRM ACQUISITION COSTS

Cost for the Rotary Transmitter and odometer from Rainhart is approximately $1,200. The PCR, DPU and software from ICC cost approximately $10,000.

MRM MAINTENANCE COST

Maintenance costs on the Rotary transmitter and odometer are minimal $100-$200 per year. The PCR and DPU were purchased in June 1984 and to date have not required any maintenance. Manufacturer support from both Rainhart and ICC has been excellent.

MAYS RIDE METER
MONTANA DEPARTMENT OF HIGHWAYS

PAVEMENT PROFILE MEASUREMENT SEMINAR
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MONTANA DOH TRAILER MOUNTED MAYS RIDE METER

EQUIPMENT REPORT GUIDE

OCTOBER 1987

A. The instrument continually logs the pavement surface by recording magnitude (1/10" increments), direction and summation of trailer axle to body excursions, together with synchronized distance measurements and landmarks. The two-wheeled 890T Mays Ride Meter Trailer was developed by the Texas State Department of Highways and Public Transportation and is available from the Rainhart Company, testing equipment manufacturer.

The purchase of an International Cybernetics (Unipro) PCR2000 (Pavement Condition Recorder) has made data collection less time consuming. A Zenith Z-171 portable computer is coupled with distance measuring equipment programmed by Unipro software to accommodate the data.

B. Pavement roughness and length are the only parameters measured with this equipment. The summation of 1/10" excursions is stored for each .1 mile of travel, then recorded on a 5-1/4" floppy diskette. The information includes:

1. Route - the particular state route being analyzed.
2. Direction - milepost direction is indicated for reference to the Pavement Management System (PMS).
3. Lane - the lane the Mays reading represents.
4. Mays count - the summation of 1/10" excursions of axle to body due to roughness.
5. Mays distance - data gathering distance traveled, which is utilized in calculation of roughness per mile.

The information is edited with an IBM PC-XT. Each 1/10"-mile reading is used to build a temporary file. Another program then calculates the pavement roughness for each distance requirement, and adds that information to the Pavement Management pavement condition file. This file is used in producing the reports needed by management.

C. The cost of the Mays Ride Meter Trailer and associated strip chart recorder was $7,900. The price of the PCR2000 (Pavement Condition Recorder) from Unipro was $9,600.

D. Operating cost of the equipment, including tow vehicle, PCR2000 and operators is $40.36 per hour. The equipment rental rate from the MDOH Equipment Management System is $3.00/operating hour for maintenance and depreciation, including the PCR2000 equipment.

JJW:kw:4y

E. 1. Operating requirements for this equipment entail a ball and socket type hitch to the tow vehicle and plug connections for trailer taillights and Mays transmitter cable.

Extra Traffic Control measures are not used, with the exception of a yellow flasher on top of the tow vehicle and a "Pass With Care" sign on the rear of the trailer.

2. A tow vehicle operator and a person to operate the PCR2000, Z-171 Zenith computer, are required.

3. Current use of the equipment in Montana is to establish Present Serviceability Index ratings on all state maintained paved highways. The PCR2000 laptop PC computer can also be detached and used wherever a 640K computer is required.

4. The Mays Ride Meter accumulates inches/mile roughness data at 50 mph. In urban areas and other restricted speed areas, the Mays meter is not used. This has caused blind spots in the system Serviceability coverage.

5. Manufacturer's support in the case of the Mays Ride Meter and trailer has been helpful. It often appears that more definite information could be furnished, yet, considering the variables in a user's operation, the manufacturer must assist where he can!

Manufacturer's support in the case of the PCR2000 has been outstanding.

6. The Mays Ride Meter and trailer are quite durable although we have found that a mandatory periodic maintenance and part replacement schedule will save on downtime. We have found reliability to be good up to the time that parts such as bearings and shock absorbers begin to wear out, then have had difficulty isolating the problems.

When maintained in good condition the Mays Ride Meter and trailer will produce repeatability of around 5%, which is adequate for our present purposes.

The PCR2000 equipment has been in operation for one year and has never caused a serious problem.

7. Moderate changes in characteristics of the tow vehicle have had very little effect on repeatability that we have been able to verify. Changes in the sensitivity characteristics of the trailer, however, such as changes in tire pressures, dramatically effect repeatability. Different shock absorbers may also cause a significant change if not the proper type.

8. Training for use of the PCR2000 equipment may be done on the job in a short time, if the new operator is trained in use of a computer. The training would be more involved and time consuming otherwise.

JJW:kw:4y

9. The collected data consisting of inches/mile roughness summations each 0.1 mile, are conveniently entered into a Pavement Management program which calculates pavement roughness for individual PMS sections of specific pavement distress.

10. The Pavement Management Section which manages the Pavement Management System operates on an annual budget of less than $200,000. The condition of 18,600 lane miles of pavement is rated every two years and reported on.

11. Productivity of the Montana Mays Ride Meter, with the PCR2000, may involve measurement and recording of roughness of 300 lane miles of Interstate highway in a 10-hour day. On Primary and less important collector routes, the daily productivity is lower.

12. a. The Mays Ride Meter equipment is used to monitor roughness of the entire Network of paved highways. Project level roughness is not measured specifically but is available through milepost separation from the Network.

    b. The Mays Ride Meter equipment is not generally used to evaluate Construction or Maintenance quality in Montana. Pavement life curve data, consisting of PSI's, is being accumulated from roughness measurements on new pavements, however.

13. The Mays Ride Meter is the first pavement roughness measuring equipment used by Montana DOH. Cost savings have therefore not been documented comparing it to another piece of equipment.

    Cost savings realized through purchase of the PCR2000 readout equipment amount to roughly $3,300 per year, consisting of savings on Mays chart paper purchases and labor in making summation calculations.

14. The impact brake has been removed from the Ride Meter trailer to eliminate the jerky motion when braking. Performance has been satisfactory thus far without it.

    Also, a reflectorized "Pass With Care" sign has been mounted on the rear of the trailer.

JJW:kw:4y

JJW:kw:4y

COX RAODMETER
NEVADA DEPARTMENT OF TRANSPORTATION

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

NEVADA DEPARTMENT OF TRANSPORTATION

MATERIALS AND TESTING DIVISION

1263 South Stewart Street

Carson City, Nevada 89712

FINAL EQUIPMENT REPORT

DEMONSTRATION PROJECT NO. 72.

Cox & Son's model CS 8000-F Roadmeter

A. Principles of operation

The Cox model CS 8000-F is a programmable roadmeter. It is a response type device in that it records how a traveling vehicle responds to a roadway surface by continuously measuring the distance between the rear axle and vehicle body. It records the deviations in vehicle body movement by incrementing registers on either side of null and accumulating them over a predetermined distance of vehicle travel which is programmable by the operator.

The data acquisition method is similar to that of the PCA roadmeter. The registers on either side of null correspond to the 1/8 inch increments of the PCA meter. The difference lies in how the registers are incremented, the Cox meter only records the peak values e.g. if the sensor detected a maximum travel of 3/8 inch, register 3 would be incremented; registers 1 and 2 would not. In addition, each register is divided in half, if the sensor measures a distance in the upper half of a register, that register is incremented twice.

Software in the unit itself uses the register data and calculates a number that is similar to the PCA count number. This feature is fixed in the unit and can not be changed, though other types of data reporting are available, such as average rectified velocity by the operators option.

Actual car body-rear axle distance measurements are obtained by use of an ultrasonic transducer. The transducer detects distance by soundings which reflect from a magnetic field. The magnetic field is moveable by a magnet mounted in an actuator which in turn is connected to the rear axle via pulleys and a small cable.

B. Parameters Measured

Only pavement roughness is measured relative to how a moving vehicle responds to deviations from a horizontal plane. The limitations are that the vehicle responds to deviations within a certain band width, dependent upon several factors, some of which include vehicle suspension, vehicle velocity, tire size and inflation pressure.

Data recording or output is by a magnetic cassette recorder and, for hard copy, a thermal printer. The record format for the magnetic cassette recorder is shown in Figure 1. Examples of printer output with various options are shown in Figures 2 and 2a.

C. Acquisition Costs

The unit was purchased in 1985. At that time the cost was approximately $16500. No additional purchase of software has been necessary. However, we did have one modification made in unit software. That modification enabled the "PCA" count number to be recorded on the magnetic tape record. The manufacturer had failed to include this item on the magnetic tape, although it was included on the paper tape output.

The unit as described herein is the standard device. The options available, that we are aware of, are built-in and are relative to the data formats and types of calculations made on the internal raw data.

D. Cost to Operate

To date we have not had this particular unit in production on an inventory basis and do not have specific data available. However, we do have pertinent data using an older Cox & Son's model CS 8000 roadmeter. These units are identical in operational requirements with the exception that only 1 person is required as driver/operator for the model CS 8000-F, whereas two people are required to operate the older model. The cost figures shown are from our experience with the model CS 8000 adjusted to reflect a single driver/operator.

Average operating cost for Cox & Son's model CS 8000-F.

equipment rental rate	\$.21 per mile
average operator wage	\$84.22 per day
perdiem rate/day	\$47.50
average miles/day tested	200
average testing cost per mile	\$.87

Note: 1. These figures do not include the amortized equipment cost.

2. The figures are based upon an overall network level which includes numerous short route segments. This causes the average daily production rate to appear artificially low. Actual production rates can range as high as 400 miles/day.

E. <u>Miscellaneous Information.</u>

1. <u>Operating requirements.</u> Prior to testing the only setup requirements are that a sufficient equipment warm-up time is allowed, normally about 30 minutes and the operator must enter the proper data for testing relative to route, highway number, milepost etc. No traffic control is required because data is collected at or near highway speed. Standard test speed is at posted speed or 50 miles per hour, whichever is less.

2. <u>Personnel requirements.</u> One person (driver/operator) is required for operation.

3. Capabilities and uses. Presently the data is used in our Pavement Management System for calculations of PSI and relative pavement condition index. No other uses are anticipated for the future.

4. Limitations or disadvantages. Some limitations were previously discussed. Probably the most serious disadvantage that we experience is lack of consistency of data from one year to the next, probably due to subtle changes in vehicle characteristics.

5. Support from manufacturer. We have had good support from the manufacturer, however, recently timeliness of repairs has been a problem.

6. Equipment durability. We have not had this equipment long enough to have a repair history yet but similar equipment we have built by Cox has been very reliable.

7. Accuracy and changes in vehicle configuration. The equipment has an automatic null update feature which compensates for slight changes in vehicle loading such as fuel consumption. We have not experienced any identifiable problem in this area.

8. <u>Training requirements.</u> We require a new employee to have approximately 2 months on the job training with the equipment as well as familiarity with the operators manual.

9. <u>Use of data.</u> Data is used in the Pavement Management System. It is additional information to help in setting priorities at the project level.

10. <u>Cost of data collection analysis and reporting.</u> See D above for data collection costs. Analysis and reporting costs are minimal, since data is recorded on magnetic tape and read directly to computer.

11. <u>Productivity rates.</u> See D above. Approximately 200 miles per day average.

12. <u>Use of the equipment.</u> Rideability data is collected and used at the network level only. Complete surveys are taken annually. PMS data is used to prioritize projects for overlay and rehabilitation. Construction control and acceptance use other types of smoothness measuring equipment (straightedge and California. Profilograph).

13. <u>Cost savings.</u> Previous equipment required two operators. This present unit is cheaper to operate. Cost savings are estimated at $6500 per year.

14. Equipment modifications. See C above.

F. Ride data.

Ride data was furnished during the open house correlation effort on October 5-8, 1987. Data furnished was uncorrected for test speed, and represents the roughness of each test site at the tested speed.

CASSETTE RECORD FORMAT

FORMAT	LAST CHAR NO. DEC	HEX	FIELD NAME
x	0	0	Record Type 1 = STD 2 = B/A 3 = ERR
bxx/xx/xx	7	7	Date: Mo/Day/Yr
bxxxxxxxx	16	10	District (or other I.D.)
bxxxxxxxx	25	19	Route (or other I.D.)
bxxxxxxxx	34	22	Pvmt Type 1 = Flex 2 = Rigid (or other I.D.)
bxxx	38	26	Meter. No.
bxxxx	43	2B	Odometer Factor
bx.xxx	48	30	Vehicle Factor
bx	50	32	Direction + or −
x	51	33	Lane
bxxxxxxx	59	3B	Sequence number
bxxxx.xx *	66	42	Begin distance
bxxxx.xx *	72	49	End distance (spaces for bridge)
bxxxx	78	4E	Raw Ride Score
bxxxx	83	53	Adjusted Ride Score (spaces if bridge apron)
bxxx	87	57	Speed
bxxx.xxx	94	5E	Trav Dist
bxxx	98	62	% Sampled
bxxx	102	66	Shock Temp (may have sign)
bxxx	106	6A	Air Temp (may have sign)
bxx:xx	111	6F	Time Hr:Min (24 hr.)
bxxxx	116	74	+ Count
bxxxx	121	79	− Count
	. . .		
bxxxx	226	E2	+ Counts
bxxxx	231	E7	− Counts
bxxxx	236	EC	Check Sum
b	237	ED	Space
CR	238	EE	Carriage return
LF	239	EF	Line feed (end of record)
16 NULL	255	FF	Trailing nulls

b = Space (Blank)

Decimal points, colons and slashes are implied and are not included in the recorded record.

All characters are null parity ASCII. The check sum is the total of the ACSII code values of characters 0 through 232. It is useful as a check of transmitted data records.

* Two or three decimal places switch selectable (see page 13).

Figure 1

REPORT FORMATS

HEADER

3/09/81	
DISTRICT	10
ROUTE	80
PVMT TYPE	2 RIGID
ODOM FACTOR	8000
VEH FACTOR	1.000
SHOCK TEMP	36
AIR TEMP	18
TIME	10:01

AUGMENTED INCREMENTAL

BEGIN DIST	7.40 *
END DIST	8.40 *
RIDE SCORE	63
SPEED 59	LANE R2
TRAVEL DIST	1.00 *
RATING DIST	1.00 *
REGISTER	COUNTS
1	176
2	143
3	64
4	36
5	4
6	4
7	0
8	2
9	1
10	0
11	1
12	1
COUNTS	3128

(Replaces PCA format:)

REGISTER	COUNTS
1	608
2	512
3	226
4	98
5	26
6	18
7	10
8	10
9	6
10	4
11	4
12	2
COUNTS	3128

SEGMENT

SEQ NO.	008000
BEGIN DIST	1.00 *
END DIST	1.30 *
RIDE SCORE	351
SPEED 55	LANE R2
TRAVEL DIST	0.30 *
RATING DIST	0.30 *
RECORD 23 WRITTEN	

SEQ NO.	0008020
BEGIN DIST	1.60 *
END DIST	1.90 *
RIDE SCORE	354
SPEED 55	LANE R2
TRAVEL DIST	0.60 *
RATING DIST	0.60 *

SEQ NO.	0008040
BEGIN DIST	1.90 *
END DIST	3.50 *
B/A RATING	1.9
SPEED 55	LANE R2
TRAVEL DIST	0.60 *
RATING DIST	0.60 *
RECORD 24 WRITTEN	

SEQ NO.	0008060
BEGIN DIST	3.50 *
END DIST	3.81 *
RIDE SCORE	26
SPEED 55	LANE R2
TRAVEL DIST	0.31 *
RATING DIST	0.31 *

SEQ NO.	0008060
BEGIN DIST	3.50 *
END DIST	3.81 *
RIDE SCORE	39
SPEED 55	LANE R2
TRAVEL DIST	0.31 *
RATING DIST	0.31 *

* Two or three decimal places CPU board switch selectable.

Figure 2

PROGRAM PRINT

LN	DIST	SEQ NO.
00	1.00	0000001
01	1.32	0080000
02	1.61	0000000
03	1.90	0008020
04	2.20	0000000
05	3.25	0000000
06	3.58	0008040
07	3.87	0008060
08	3.81	B0008080
09	3.90	B0000000
10	4.20	0008100
	*	

CALIBRATION

3/09/81

DISTRICT	10
ROUTE	80
PVMT TYPE	2 RIGID
ODOM FACTOR	8000
VEH FACTOR	1.000
SHOCK TEMP	36
AIR TEMP	18
TIME	10:01
DISTANCE	1.000
SPEED	55
ODOM PULSES	8000

* Two or three decimal places CPU board switch selectable.

Figure 2a

MAYS RIDE METER (TRAILER-BASED)
B&K ACELLEROMETER
FHWA, WESTERN DIRECT FEDERAL DIVISION

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

PAVEMENT PROFILE MEASUREMENT SEMINAR

EQUIPMENT REPORT

WESTERN DIRECT FEDERAL DIVISION

FEDERAL HIGHWAY ADMINISTRATION

Date: October 1, 1987

Richard G. Wasill
Project Development Engineer

#4399J

INTRODUCTION

The following equipment is or has been utilized by the Western Direct Federal Division (WDFD) of the Federal Highway Administration (FHWA) to evaluate pavement smoothness.

- Mays Ride Meter
- 10 Foot Rolling Straightedge
- California Profilograph
- Mays Ride Meter Test Trailer Modified to Include a Bruel and Kjaer Model 2231 Integrating Meter (Accelerometer)

The Mays Ride Meter is a device used by many agencies for evaluating pavement roughness. It is now being used by the WDFD to measure asphalt concrete pavement smoothness. A pavement surface rideability value is determined that serves as the basis for determination of end of construction pay factors based on established tolerance limits.

The Rolling Straightedge and the Profilograph are not used routinely. At this time no attempt has been made to include measurements from these devices in the pavement rideability value specification.

The Mays Ride Meter has been used as a tool to measure post construction smoothness on a number of projects with the result that improved surface smoothness has resulted. This is not only verified by generally improved rideability values but also by subjective evaluation of involved WDFD construction personnel.

The repeatability of the Mays Ride Meter data has been questioned by some researchers. In the interest of learning more about how this device works and the impact of various components on the results, a comprehensive evaluation was conducted at the USDOA Laboratory at San Dimas, California. During this testing, it was found under certain conditions the Mays Ride Meter could be artificially excited to the point where the resulting data was not repeatable.

In order to overcome this potential problem, an accelerometer was mounted on the trailer to serve as an additional measurement device. It was suggested this device with further development may be an appropriate method to evaluate pavement roughness.

In a recent study, WDFD collected data on selected asphalt concrete pavement sections with all four of the devices previously described. This data is being evaluated and will be the subject of a future report.

The document describing the pavement profile measurement seminar provided a suggested equipment report format.

We have attempted to follow this format and have provided brief descriptions below with the detailed information in the attachments.

DESCRIPTION OF ROUGHNESS TEST DEVICES

A. **Describe and document the principles of operation of the various categories of equipment and peripherals evaluated. Discuss software available and its application.**

Appendix A contains a detailed description of the Mays Ride Meter as part of the specification being used to evaluate recently completed asphalt concrete paving projects for smoothness. The software and the other items requested are also described in the specification and the attachments thereto.

Also included in Appendix A is a brief description of the accelerometer system. This equipment is described in a short paper by Paul A. Smith of Bruel and Kjaer Instruments, Inc. Associated software is also briefly described. This device is at this time experimental and is not being used as part of the end of construction pavement rideability evaluation.

B. **Describe the pavement condition parameters measured by the device (i.e., roughness, rutting, distress, cross slope, cracking, etc.)**

1. **Describe output and format of output.**

2. **Processing required to get output.**

The devices described in Item A are used to measure pavement smoothness. The Mays Ride Meter data is converted into a rideability value. This is described in Appendix A.

The output and format of the output are shown on Figure 3 and Figure 4 of Appendix A for the Mays Ride Meter. An example of the output for the accelerometer is shown as part of the previously referenced report. The processing needed to arrive at the desired output is described in the specification (Appendix A) and shown in the flow chart, Figure 2 (Appendix A).

C. **Acquisition costs of equipment (from manufacturer):**

1. **Hardware**

2. **Software**

3. **Standard equipment and options available**

The costs for the equipment and the year purchased are shown in tabular form in Appendix B. It should be noted no attempt has been made to convert the original purchase price into today's dollars.

D. **Average costs to operate and maintain equipment.**

Detailed information is not available on the cost to operate and maintain the Mays Ride Meter. Roughly, one quarter of a man-year is involved in normal operation and maintenance. This does not include ongoing research efforts in the area of pavement smoothness. In a normal year, six projects are evaluated at the end of construction to determine rideability values. In addition, existing projects in the area are rerun to pick up changes in surface smoothness to determine the change from the end of project runs.

No charge is made for the Mays Ride Meter equipment, so the only equipment cost is for the pickup. Since this pickup is assigned to this operation, the total yearly cost is borne by the Mays Ride Meter activities.

E. Describe and document your experiences with the equipment as it relates to the following:

1. Operating requirements such as setup and traffic control.

The operating and traffic control requirements are covered in Appendix A and in the data included in Appendix C.

2. Personnel needs for operation of the equipment.

An operator is required plus appropriate flagging if needed for safety.

3. Capabilities and uses that could be made of the equipment by the Cooperating Agency.

The equipment can be utilized to determine pavement surface smoothness (rideability) at the conclusion of construction to determine a smoothness pay factor. It can also be utilized to track pavement surface roughness changes over time and for comparative studies to evaluate the impact of varying construction equipment on surface smoothness.

4. Limitations or disadvantages associated with the equipment.

The Mays Ride Meter equipment as presently setup is subject to the influence of a number of variables that are difficult to quantify and isolate. These variables affect the repeatability of the output data. While the resulting smoothness data is quite reproducible on successive runs on a given day on a specific piece of pavement, there is some difference in the data if comparative runs are made at a later date.

5. Manufacturer's support in resolving problems.

The manufacturer has been cooperative and helpful in solving normal, routine types of problems.

6. Equipment durability, reliability, and repeatability.

The Mays Ride Meter is a relatively durable piece of equipment and is generally reliable when used as WDFD utilizes it. There is some need for further development of the device or development of a modified device such as the accelerometer modification described previously to improve the repeatability of the surface roughness measurement over time. The repeatability of the rideability data is quite good on successive runs done during a given day.

7. **Effects of various vehicle loadings or changes in vehicle characteristics on the accuracy or repeatability of measurements.**

The Mays Ride Meter has been previously mounted in a van and is now trailer mounted. The difference in vehicle characteristics, at least based on this limited experience, has significantly reduced the variables. The hitch height for the trailer was also found to have an impact so a hitch configuration was devised so the hitch height was level to within 1/8 inch. Any change in the center of gravity of the equipment or vehicle load also has some impact. The San Dimas study looked at the variation in suspension and shock characteristics on the repeatability of the results. It was found that changes in suspension system characteristics, as well as the type and condition of the shocks, influenced the output data. The WDFD tried different types of shocks and ultimately determined for the purpose for which the device was being used the manufacturer's recommendation on shocks was the most appropriate.

8. **Training necessary for use of the equipment.**

An operator's manual has been developed. Normally, one run with a trained operator is sufficient to learn to operate the Mays Ride Meter. It has been possible for operators to learn to run the equipment with no training other than review of the operator's manual.

9. **Usefulness and reasonableness of collected data.**

Based on comparison of asphalt paving projects tested for smoothness (rideability value) in 1985 and 1986 for specification compliance (refer to Appendix A), the collected data appears reasonable. The usefulness can be gauged by the subjective evaluation of the construction personnel's reaction. It is their feeling that the pavement rideability value requirement has resulted in smoother pavements and more uniform pavements. The fact the requirement is in the plans has apparently forced the contractors to be more aware of the things that affect surface smoothness and has caused them to plan and organize their projects so as to create a more uniform product.

10. **Average costs of data collection, analysis, and reporting.**

Since the WDFD covers a very large land area, the cost of data collection is very dependent on the distance to a project (mobilization). In addition, in a normal year six projects are evaluated at the end of construction. The actual testing requires roughly 30 minutes per mile and the data reduction and final computation another 30 minutes per mile of road tested. The testing cost, exclusive of travel, is roughly $20 per hour. For additional detail refer to Appendix C.

11. **Equipment productivity rates (i.e., miles/day).**

    This data is shown in the table included in Appendix ~~A~~ C. The Mays Ride Meter test time is approximately 30 minutes per mile.

12. **Document use of the equipment for the following:**

    a. **Inventory monitoring/condition survey**

       (1) **Network level** - Not used for this purpose.

       (2) **Project level** - Used only to look to changes in a specific project, not for use as an aid to pavement management at the network level.

    b. **Construction control and acceptance**

       (1) **New Construction** - May be used as a means of establishing payment, asphalt concrete.

       (2) **Rehabilitation** - May be used as a means of establishing payment, asphalt concrete.

       (3) **Reconstruction** - May be used as a means of establishing payment, asphalt concrete.

13. **Cost savings which you have realized by using the equipment.**

    Cost savings are not quantifiable. If the implementation of the rideability value is as observed by the construction personnel and in fact a more uniform pavement is resulting, then increased pavement life is possible. Only time can answer whether this has in fact occurred.

14. **Detail any modifications made to the equipment.**

    The clutch drive pulley for the Mays Ride Meter transmitter has been modified to make it more reliable. The impact of the trailer suspension system and the type and condition of the shocks has been evaluated; however, the manufacturer's recommendations are currently being followed. As noted previously, the hitch height of the trailer has been determined to be important and is set as close to level as possible.

F. **Supply ride data in appropriate format for correlation and analysis. Other pavement related data collected in conjunction with the correlation effort shall be submitted to the CDOH Research Branch.**

This information will be furnished after the field testing has been completed and the data analyzed.

APPENDIX A

SECTION 4.240

Standard Method of Test for
DETERMINATION OF PAVEMENT RIDEABILITY VALUE
WDFD TEST PROCEDURE

1. SCOPE

1.1 This pavement management test method is used to determine a pavement surface rideability value. The value may be used: in comparative studies involving construction equipment; in determining present serviceability ratings; and in establishing construction workmanship incentive/ disincentive awards.

2. EQUIPMENT

2.1 Sensor - A Mays Ride Meter™ transmitter mounted on a reference platform directly over a testing axle with a vertical connecting rod secured to the axle with a ball connection. The transmitter shall be capable of sensing vertical axle movement and transmitting the movement to a recorder.

2.2 Recorder - A Mays Ride Meter™ recorder continually available to an operator, and capable of converting axle movement data to a graphic form. The recorder may include: (a) An odometer connection, capable of indicating preset distance increments at their appropriate graphic location; and (b) A device that will permit the operator to identify and record specific landmarks simultaneously with the happening.

2.3 Test Vehicle - The reference platform shall consist of the body of a single axle two-wheel trailer having a gross weight of 1700 ± 50 pounds and a low profile. The weight shall be center over the axle in such manner that not more than 150 pounds is carried at the hitch. The axle shall have spiral or coil springs, and movement shall be dampened with shock absorbers rated heavy-duty with a 1-5/8 inch bore. Tires shall conform to AASHTO M 261.

2.4 Towing Vehicle - The towing vehicle shall have a suitable trailer hitch, and a 12 volt electrical source for operating test equipment.

2.5 Air Pressure Gauge - A common stick type tire pressure gauge with one pound graduations, or a similar instrument.

3. OPTIONAL ACCESSORIES

3.1 Microcomputer - A Pavement Condition Recorder (PCR) with a printing unit may be added to the recording system at the option of the operator. Such unit should be capable of producing a printed record of the test including the following data:

DATE
TIME of day
ROUTE designation
SPEED at which test is run
BEGIN M.P.
DIRECTION
OPERATOR
DIST. INCR. (subtotals at set intervals)
DIST. COEF. (distance calibration factor)
WORK COEF. (PCR to MAYS factor)
TIME of test run in seconds
END M.P.
NET LENGTH of tested segment
TOTAL COUNT
RIDE RATING (adjusted value per mile)

3.2 When the microcomputer is used, the NET LENGTH and TOTAL COUNT listed on the SUMMARY output shall be the components used in the computation of an average RIDEABILITY VALUE. In such case the graphic recorder tracing (Section 2.2) will be considered only as a supplemental record.

3.3 Thermometer - An infrared non-contact type thermometer with $2^{o} \pm C$ accuracy, or a similar instrument.

3.4 Thermo-Couple - The test vehicle may be equipped with a remote sensing device to monitor shock absorber temperatures during testing with $2^{o} \pm C$ accuracy.

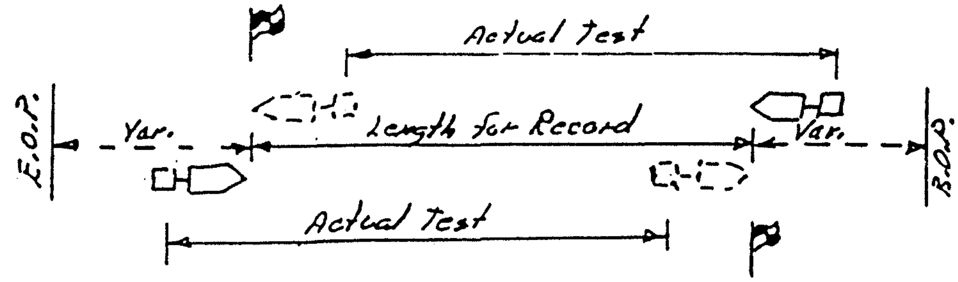
3.5 Cruise Control - The towing vehicle may be equipped with a test speed controlling device.

4. TEST PREPARATIONS

4.1 Trailer tire pressure shall be adjusted to 32 ± 2 psi, all components shall be turned on, and the vehicles shall be operated for a warm-up period of approximately 20 minutes, or until shock absorber temperature has stabilized, before testing begins.

4.2 Suitable control flags or markers shall be placed at the beginning and end of the proposed test segment, and at such other intermediate points as may be desired. As flags are placed, the length of the vehicles, the distance required to attain test speed, and stopping distance should be considered (Fig. 1). The length for record need not equal the exact project length.

Figure 1.



NOTE 1: Flags should be placed at the beginning and end of project, except where additional room is needed to obtain test speed or for stopping.

4.3 Provision shall be made for traffic control, including warning signs and flaggers, as appropriate.

4.4 Finally, the operator shall make a preliminary pass over the test site to become familiar with markers, traffic control provisions, the relation of design speed to test speed, and other conditions.

5. PROCEDURE

5.1 All equipment used in the test shall be operated in accordance with the manufacturer's instructions and recommendations for the specific piece and model.

5.2 After entering record data, warming up equipment, and adjusting tire pressure, the test run may begin. (Note: Tire pressure is expected to increase during testing. It should be checked and adjusted to the specification before each run.)

5.3 Approach the start flag at the designated speed and activate the Mays recorder before reaching the flag to start the graph. As the flag is reached, identify the point with the landmark device. (Note: Starting the PCR will cause the Mays landmark device to function and mark the beginning of the test.) Record or mark any intermediate points as they are intercepted. Identify the end of test as the flag is reached, and then deactivate the Mays recorder.

5.4 The test vehicle shall be operated at the specified speed in the approximate wheel paths of the lane being tested. The wheel path is the area of the lane, which can normally be expected to be used by traffic.

5.5 If a test run is disrupted for any cause (example - slow moving vehicle ahead) the segment, as defined by control flags, shall be re-run, or the entire test may be re-run at the operator's option.

NOTE 2: The PCR has the capability to measure, record, and compute a complete run with interruptions. The output paper tape will carry the following display identification with the relative mile post and count subtotal:

B Beginning
I Increment
L Landmark
H Hold (at the beginning of segments to be deleted)
C Count Active (resume after Hold)
E End

5.6 Figure 2 is a pictorial overview of the WDFD Ride Meter system. Everything begins at the Vehicle Sensor. Fully reliable rideability values can be obtained with only the sensor and Mays graphic recorder operational.

NOTE 3: Single operator precision (variance in transverse roadway location and fluctuation in speed) during testing, may be compensated for by averaging three test results.

NOTE 4: Variability of mechanical equipment due to continuous motion is not considered to be a factor in the test results.

6. IDENTIFICATION

6.1 The following information should accompany each run or set of runs. Values may be individual or may be expressed as a range at the option of the operator.

Job Identification
Operator
Date
Time
Direction
Beginning Point
Ending Point
Tire Pressure
Tire Temperature
Pavement Temperature
Weather
Test Speed

7. COMPUTATIONS

7.1 Calculate the pavement Rideability Value as follows:

$$\frac{\text{Inches of Recorder Graph}}{\text{Lane Miles Tested}} = \text{Rideability Value}$$

Where:

The INCHES OF RECORDER GRAPH are measured manually. Each pertinent segment of a run shall be measured to the nearest 0.02 inch, and the sum of the subtotals shall be that used in the computation. (Note: Some adjustment of landmark graphic locations recorded during testing may be required due to graph pen carryover.)

The number of LANE MILES TESTED shall be the pertinent distance measured to the nearest 0.01 mile, based on survey stationing. When stationing is not available, odometer values shall be used and noted as such.

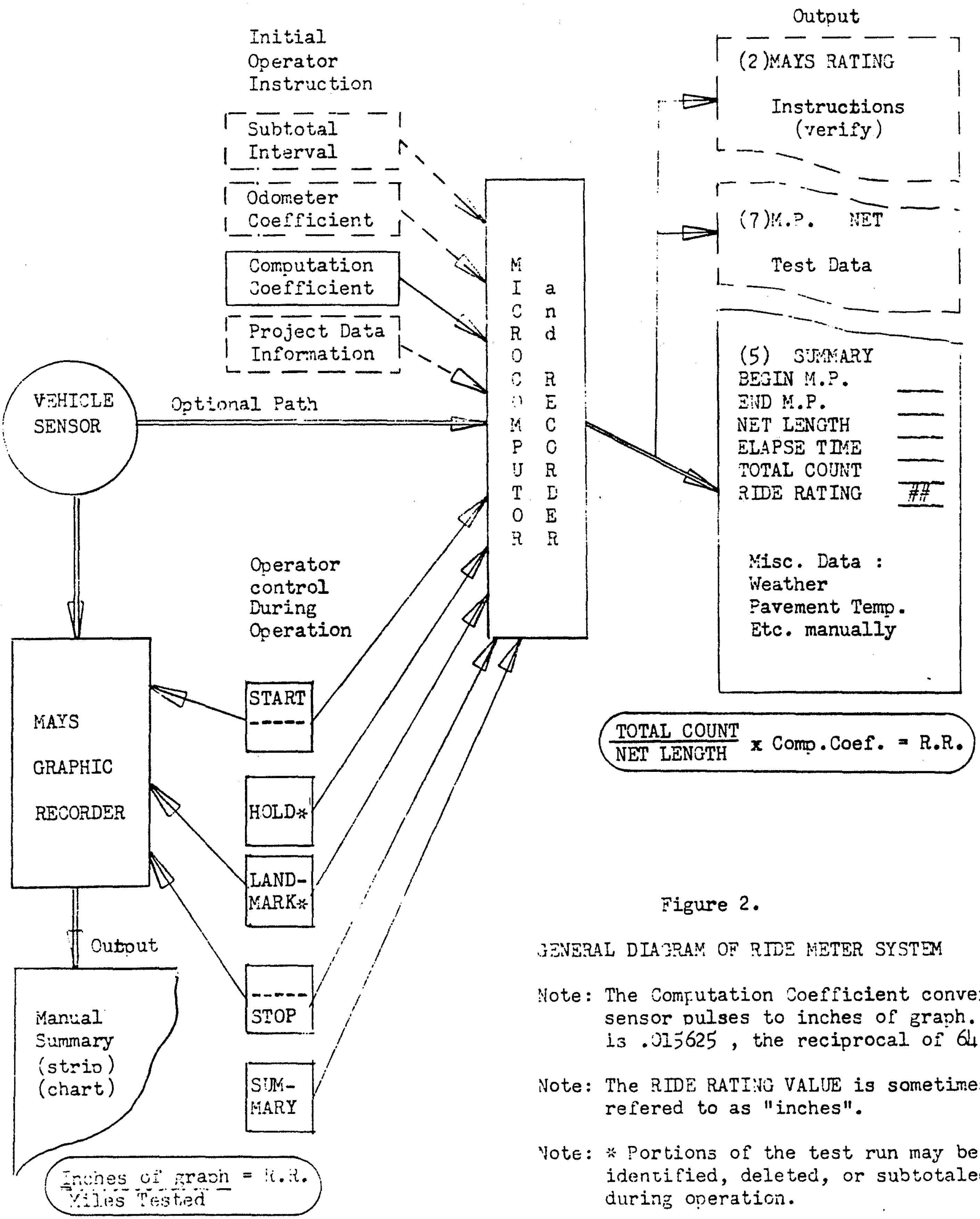


Figure 2.

GENERAL DIAGRAM OF RIDE METER SYSTEM

Note: The Computation Coefficient converts sensor pulses to inches of graph. It is .015625 , the reciprocal of 64.

Note: The RIDE RATING VALUE is sometimes refered to as "inches".

Note: * Portions of the test run may be identified, deleted, or subtotaled during operation.

7.2 Report pavement Rideability Value to the nearest 0.1 inch. When the average of a series of tests is to be reported, like data shall be summed and the totals used in the computation. Figure 3 is a form that is suitable for reporting.

7.3 When the microcomputer is used in the testing process, computation of the pavement Rideability Value is accomplished within the PCR unit, and the value is reported on the PCR output tape as the RIDE RATING. The following provisions are included within the PCR system:

Transmission actuated odometer pulses are modified by a factor for accuracy of $\pm$ 0.2 percent, and reported on the output as NET LENGTH in miles.

Mays transmitter impulses are received, accumulated, and reported on the output as TOTAL COUNT. Since the Mays recorder would plot these impulses at the rate of 64 per inch of graph, PCR applies a factor (reciprocal of 64) and computes and reports the RIDE RATING on the output as follows:

$$\frac{\text{Total Count}}{\text{Net Length}} \times 0.015625 = \text{Ride Rating} = \text{Rideability Value}$$

7.4 Figure 4 consists of samples of the field data output.

RIDEABILITY VALUE CALCULATION

Project: ____

Test Date: ____________________ Test Crew: ____________________

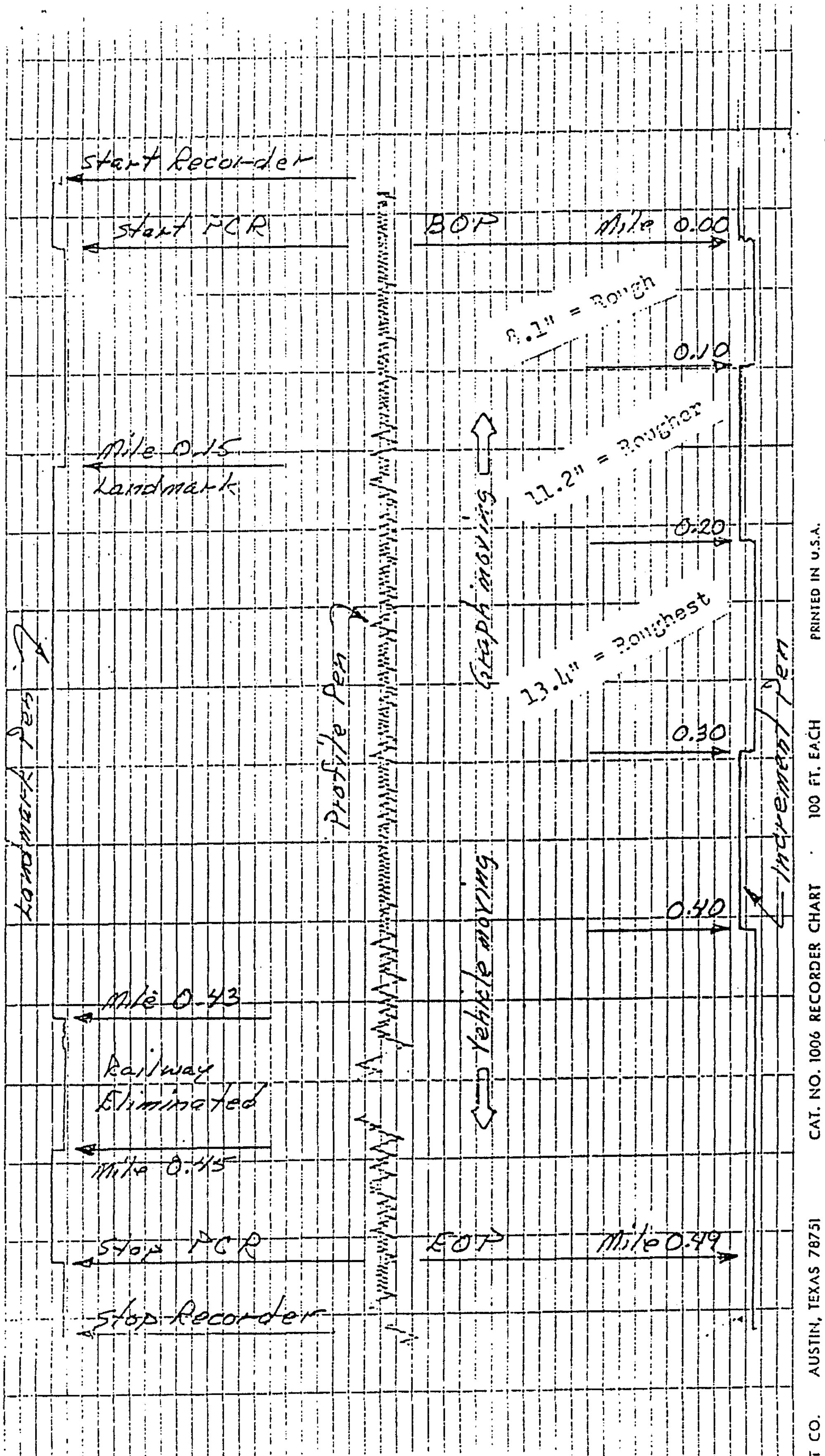
Speed: ____________________ Project Length: ____________________

	Lane/Direction	Miles	PCR Count	or	Mays Inches	Rating
Run #1						
Run #2						
Run #3						
Run #4						
Run #5						
Run #6						
Total						

$$\text{Rideability Value} = \frac{\text{Total Count}}{\text{Total Miles}} \times \frac{1}{64} \quad \text{or} \quad \frac{\text{Total Inches}}{\text{Total Miles}} = \_\_\_\_\_\_$$

Comments/Notes: ____

Figure 3



NOTE: 52 CNT per 1/10 mile = 520 CNT/M.
520/64 = 8.1 MRM Inches per Mile

Figure

```
[2] MAYS RATING
DATE                021887
TIME                  1300
AGENCY/STATE           145
ROUTE                   14
SECTION                  1
SURF/SPEED              30
BEGIN M.P.            0.00
DIRECTION                N
LANE                     1
SELECT DCF              01
RECORD MODE              1
OP/VEH/MAYS           1928
DIST. INCR.            .10
DCF:1               .16706
CONSTANT:1               0
COEF.:1            .015625

[7]M.P.    NET        CNT
B   0.00   00000021
I   0.10    0.10       52
L   0.15    0.05       38
I   0.20    0.04       34
I   0.30    0.09       86
I   0.40    0.10       73
H   0.43   00005941
C   0.45   00006208
E   0.49    0.07       77

NET LENGTH            0.47
ELAPSE TIME       00006624
TOTAL COUNT           360.

[5]  SUMMARY
BEGIN M P             0.00
END M.P.              0.49
NET LENGTH            0.47
ELAPSE TIME       00006624
TOTAL COUNT           360.
RIDE RATING           12.0

[4]
```

Federal Highway Administration
Western Direct Federal Division

Standard Special Provision for use with the FP-85 (Standard Specifications FOR CONSTRUCTION OF ROADS AND BRIDGES ON FEDERAL HIGHWAY PROJECTS) when a pavement rideability value is to be used in determining payment.

****
USE THE FOLLOWING SUBSECTION WHEN SURFACE ROUGHNESS SPECIFICATION IS REQUIRED.

GEOTECHNICAL SECTION TO DETERMINE SPEED AND TESTING COSTS. PAYMENT/DEDUCTION MONIES: USE 10 PERCENT OF ASPHALTIC PAVEMENT ITEM 401(1) FOR 0 TO 4.0 AND 10.1 TO 12.0, ROUND TO NEAREST $1,000 UP TO A MAXIMUM OF $30,000. USE ONE-HALF OF 10 PERCENT DOLLAR VALUE FOR 4.1 TO 6.0 AND 8.1 TO 10.0.
****

401.21 Acceptance Sampling and Testing of Asphaltic Concrete Mixture (Surface Tolerance). Delete the text of this subsection and substitute the following:

The final course of the traveled way will be tested for surface roughness by the Government using a Mays Ride Meter™. The testing will be completed within fourteen (14) calendar days after the Contractor notifies the Engineer that paving is complete.

An average surface roughness value in inches per lane mile will be determined by making three (3) passes with the Mays Ride Meter™ at approximately ______ miles per hour in the direction of traffic flow for each lane of the traveled way. Roughness attributed to bridge decks or other causes beyond the control of the Contractor will not be included in the average surface roughness value.

The average surface roughness value will be used to determine incentive payments or disincentive deduction of monies. See Table 401-3 below.

Table 401-3

Average Surface Roughness Value (inches/lane mile)	Incentive/Disincentive + / -
0 to 4.0	+ $________
4.1 to 6.0	+ $________
6.1 to 8.0	None
8.1 to 10.0	- $________
10.1 to 12.0	- $________
12.1 and greater	Unacceptable - corrective action required

When the average surface roughness value is less than 12.1, no corrective action will be permitted without written approval of the Engineer.

When the average surface roughness value is equal to or greater than 12.1, corrective action shall be taken and shall continue until the average surface roughness value is less than 12.1.

Corrective action shall consist of one or more of the following:

- Remove and replace the surface course.
- Place an overlay course at least 1-1/2 times as thick as the maximum sized aggregate in the asphaltic mixture.
- Grind the pavement surface with approved equipment. The thickness of pavement removed shall not exceed 1/4 inch.

All corrective work shall be completed within ten (10) working days following the date the initial average surface roughness value was determined.

Upon completion of corrective work, the Government will test the final pavement surface and determine a new average surface roughness value. This test will be completed at no cost to the Contractor. All additional tests requested will be at the expense of the Contractor. The Contractor shall reimburse the Government $____________ for each additional test.

All costs for corrective work to improve surface roughness shall be borne by the Contractor. No compensation or adjustments in contract time will be made for corrective work.

The above surface roughness testing does not preclude localized correction at joints or other areas where variation of the surface exceeds 3/16 inch between any two contacts of a 10-foot straightedge in either transverse or longitudinal directions.

The lump sum incentive payment or lump sum disincentive deduction of monies due the Contractor will be based upon the final surface roughness value established for the project.

1986 PROJECT RIDEABILITY SUMMARY

PROJECT NUMBER/NAME	↔↕	PASS #1 R.V.	PASS #2 R.V.	PASS #3 R.V.	PASS #4 R.V.	PASS #5 R.V.	PASS #6 R.V.	RANGE	TOTAL MILES TESTED	AVERAGE RIDE VALUE	AWARD	REMARKS
Wyoming Proj. R-AD-0010(04)	S	5.1		4.6		5.7		1.1	16.8	4.8"	$ 6,000	5/21/86
Peacekeeper Improvements	N		4.3		4.9		4.2	.7				
Wyoming Proj. R-AD-0010(007)	S	9.1		8.8		9.5		.7	8.0	7.9"	none	5/21/86
Link 182	N		9.9		9.9		10.0					
Peacekeeper Improvements	W	8.7		8.8		8.7		.1	19.7			
Link 185	E		6.4		6.9		5.7	.7				
Wyoming Proj. R-AD-0010(007)	N	5.9		8.2		7.8		2.3	6.0	7.5"	none	6/17/86
Link 170	S		4.6		4.3		4.8	.5				
Peacekeeper Improvements	N	8.6		8.2		8.5		.4	18.8			
Link 171	S		8.6		8.5		9.0	.5				
	N	7.5		7.7		7.7		.2	36.5			
Link 172	S		7.7		7.5		7.7	.2				
Montana FHP 12-1(2)	N	5.4		5.3		5.4		.1	85.6	5.5"	$10,000	9/11/86
Whitefish-Eureka Hwy.	S		5.7		5.6		5.7	.1				
Montana FHP 73-1(1)	S	2.4		3.1		4.0		1.6	27.8	3.5"	$10,000	9/23/86
Wise River-Polaris Hwy.	N		3.2		4.0		4.6	1.4				
Grand Teton N.P. Proj. 10-1(1)	N	6.8		7.0		7.3		.5	27.0	7.4"	none	10/1/86
East Side Highway	S		7.4		7.7		8.1	.7				
Washington FHP 102-1(1)	N	7.2		6.8		7.1		.4	5.9	7.8"	none	10/15/86
White River Road	S		8.6		8.7		8.5	.2				
Oregon FHP 1-1(1)	E	10.8		10.8		11.3		.5	6.0	11.3"	-15,000	10/21/86
Three Rivers Hwy.	W		11.7		11.7		11.7	.0				
Oregon FHP 109-1(1)	W	8.3		8.3		8.2		.1	43.2	8.6"	- 5,000	10/23/86
Willow Creek Road	E		9.1		8.7		9.0	.3				
								Average 0.5	301.3	Ave.of 9= 7.1	$ 6,000	0.5/7.1 = 0.07 Say ± 4%

PROJECT RIDEABILITY SUMMARY

PROJECT NUMBER/NAME		PASS #1 R.V.	PASS #2 R.V.	PASS #3 R.V.	PASS #4 R.V.	PASS #5 R.V.	PASS #6 R.V.	RANGE	TOTAL MILES TESTED	AVERAGE RIDE VALUE	AWARD	REMARKS
Wash. FHP 20-1(1) & FLH 20(29) Wauconda - Kettle Falls Hwy.	W	5.66		5.61		5.86		.25	83.61	5.5	$15,000	7/17/85
	E		5.23		5.13		5.40	.27				
Oregon FHP 111-1(1) Ukiah-Granite	N	1.46		1.77		1.82		.36	28.64	2.2	$20,000	7/18/85
	S		2.64		2.57		2.69	.12				
Oregon FHP 146-1(2) Palmer Junction Rd.	N	3.79		3.81		4.10		.31	46.85	4.5	$10,000	9/10/85
	S		4.29		4.59		4.69	.40				
Wyoming FHP 4-1(1) & FLH 15(11) Beartooth Highway	N	2.41		2.40		2.52		.12	13.71	2.8	$21,000	9/24/85
	S		3.02		3.06		3.17	.15				
Washington FHP 21-1(2) Inland Empire Hwy.	N	1.82		1.86		1.80		.06	40.89	1.8	$20,000	11/1/85
	S		1.73		1.69		1.77	.08				
Wyoming Project R-AD-0010(006) Peacekeeper Improvements	N	2.77		2.87		3.03		.26	27.46	2.8	$10,000	11/5/85
	S		2.50		2.77		2.87	.37				
Washington FHP 3-1(4) Quinault Hwy.	N	3.12		2.78		3.07		.34	10.95	3.0	$10,000	11/14/85 (incl. bridges)
	S		2.95		3.19		2.89	.30				
									252.		$106,000	
								Average .24		Avg. of 7=3.23		$\frac{.24}{3.23} = 0.075$ Say ± 4%

EXPERIMENTAL METHOD OF CALIBRATION
MAYS RIDE METER TRANSMITTER
WDFD PROCEDURE

8. CALIBRATION

8.1 Field Calibration - There is no field calibration of the MRM Recorder or the PCR Recorder, except for the odometer feature covered separately. The MRM Transmitter should normally be calibrated to provide the lowest value obtainable at the test site and test time. The response generated by some pavements may hang the sensor in such a manner that it does not return to zero between the suspension strokes. This condition can be recognized by observing the trace on the recorder, and is grounds for modifying the normal instrument setting.

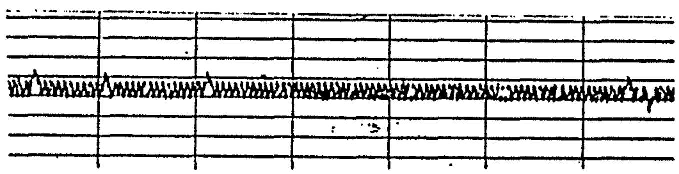


Figure 1. A trace showing a sensor problem.

8.2 Procedure - Install the calibration arm on the transmitter drive pully, and place the adjustable scale (3 division side out) at the end of the arm. Turn on the recorder and place it where it can be heard from the rear of the trailer. (NOTE: Low power may cause problems, and it may be necessary to run the engine.)

Work the trailer suspension by moving the bumper (down for a compression stroke and up for an extension stroke) ten times being careful not to damage the arm. One should be able to hear the recorder click.

From the side of the trailer, where the arm and scale are clearly visible, compress the system one click, note the related location of the arm and scale, and release the system. A second click should be heard as the system returns to rest.

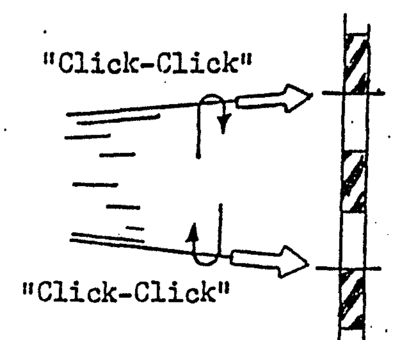
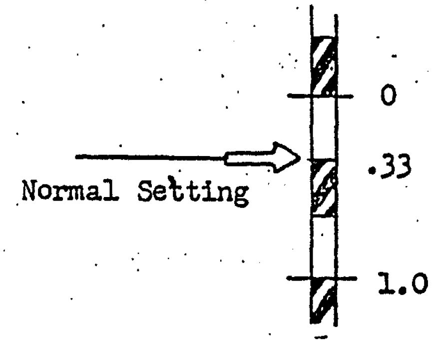


Figure 2.

Set the bottom of the three-division scale in line with the point observed above. If the setting is correct, the recorder should "click-click" when the system is compressed to the bottom of the scale and released, and again as it is extended to the top and released. If not, reset the scale and try again.

Work the system several times at the center of the bumper. The arm should come to rest at approximately the same point each time.

Release the thumb screw lock mechanism on the drive pully. Using an allen wrench adjust the arm to the normal setting location on the scale, and tighten the lock mechanism. From the center of the trailer work the system several times to confirm the arm setting, and that the top to bottom set of the scale is still ligned-up.



NOTE: The movement dampening of the shock absorbers in compression is one-half that of extension. With the top of the three-division scale as "0" and the bottom as "1", the arm should normally be set at ".33".

Figure 3.

NOTE: The suspension does not usually return to the same point when operated from the side, but almost always does whem operated from the center. Side operation just makes it easier to read the scale-arm relationships.

NOTE: The pressure spring on the arm adjustment may not function. Some finger pressure ma y be required when the screw is backed out.

Road Roughness Rating System

Presented to:

The Federal Highway Administration
and
U.S. Forest Service, Vehicle Group

By:

Paul A. Smith, F.A.E.
Bruel & Kjaer Instruments, Inc.

CONTENTS

1.0 BRUEL & KJAER ROAD ROUGHNESS RATING SYSTEM

1.1 Overview

1.1.1 System Considerations

1.1.1.1 This application of the Bruel & Kjaer Model 2231 Integrating Meter was designed to give a accurate, repeatable descriptor of the quality of a roadway under test. This was effected by displaying a time-weighted average of the RMS acceleration seen at the test trailer axle. The units displayed are decibels (dB) of acceleration, referenced to the level set in the meter; ie., 0 dB = .25g RMS therefore a calibrated 1 g input registers 20 log (1g/.25g), or ≃ 12 dB. While not directly equivalent to the "Mays Ride Meter" numbers of a given road, the Road Roughness Rating System (RRRS) ratings were of a similar scale, and could be likely correlated via the RMS acceleration.

1.1.2 Background

1.1.2.1 After initial contact by the U.S. Forest Service's Vehicle Design personnel, the RRRS system was proposed as a method to reduce the variability of the presently used system. The system in used appeared to exhibit random errors likely generated in the transducer section of the unit - a device which optically/mechanically converted axle displacement into a pulse train for further analysis. This unit was prone to dither effects depending upon the initial location of the static setting adjustment. As recent studies have been focusing on the RMS acceleration descriptor (a unit proportional to the energy content in a time-varying signal) as both a measurement and a calibraion means, it was chosen as the basis of the RRRS system. For better dynamic range, that is, the ability to adequately display a wide variety of road roughnesses on the same meter scale, a decibel conversion was performed in the meter. The resulting system enables measurements to be made on widely differing pavement surfaces without adjustment.

1.1.3 Additional Capabilities

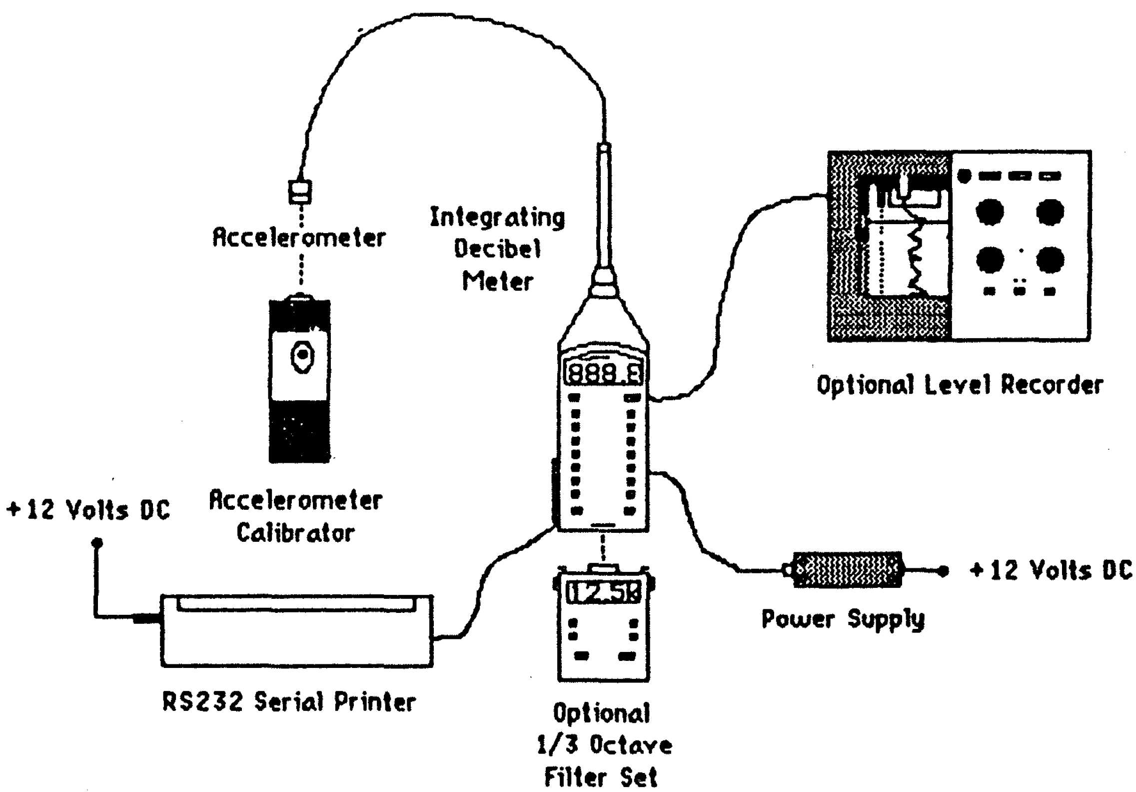
1.4 Summary

1.4.1 The RRRS system appears to be a viable investigative tool to better quantify the vibration experienced at the axle of the towed trailer. Results have been shown to be reasonable and repeatable. The transducer should prove to be durable and long–lived with proper handling care; periodic calibration will assure the operator of continued proper performance. If desired, true average RMS acceleration is available (in non–dB form) through simple calculation, and with subsequent frequency analysis or electronic integration, velocity and displacement could be found.

Although not purpose-designed for the single vehicle operator, the currrent system configuration can be used by one man – the addition of a recorder or microcomputer would necessitate a passenger to assist. The modification of the system to accept a pulse/contact–closure from an electronic tachometer would refine the operation, thereby giving an output directly tied to distance, versus dependent upon a constant known vehicle speed. Alternatively, an analog recorder can monitor the real–time output of the system, and display a timing mark or "birdie" it the distance marks.

I speak for myself and Bruel & Kjaer when I thank you for the opportunity to be involved with this system, and look forward to providing support in the future as this research continues. Good luck on the balance of the project!

RRRS System Diagram



Meter: Bruel & Kjaer Model 2231
Accelerometer: Bruel & Kjaer Model 4370
Printer: Ergo Systems Model HUSH80
Opt. Filter: Bruel & Kjaer Model 1625
Opt. Recorder" Bruel & Kjaer Model 2317

Federal Highway Administration
Western Direct Federal Division

ACCELEROMETER OUTPUT DATA

Two formats are used in the WFD research. The manual format provides a test length grand total without any segmented subtotals. The Automatic format will record segmented subtotals (which are only a portion of the data, since no data is recorded during printing) without a grand total.

AUTOMATIC MODE

FFL	20.0	14.9	13.4
FFL	21.0	15.0	13.1
FFL	21.1	15.2	13.6
FFL	21.5	15.6	13.8
FFL	23.0	15.9	14.2
FFL	22.5	15.9	14.7
FFL	23.9	16.2	14.6
FFL	23.2	16.9	15.2
FFL	22.5	17.0	14.9
FFL	25.7	16.4	15.2

The SLM measures in the time mode. In order to obtain subtotal values within a given mile, one must set a test time that approximates the subtotal length in distance.

The SLM does not record while it transmits to the printer, therefore, about 2 seconds of sata is lost out of eash subtotal.

One mile at 45 MPH = 80 seconds -
Ten 6 sec. subtotals = 60
Nine 2 sec. prints = 18
Aproximately 80

MANUAL MODE

-- B&K SLM TYPE 2231 --

Set Up: F. F. L.

MAXP	26.9 dB
MAXL	16.6 dB
MINL	- 8.0 dB
SEL	30.7 dB
LEQ	11.7 dB

No overload.

No reset of Max/Min.

Elapsed Time: 00:01:20

No. of interrupts: 0

One mile value at 45 MPH.
Note that test time is recorded, and that there have been no interruptions during the testing period.

APPENDIX B

Federal Highway Administration
Western Direct Federal Division

Pavement Rideability Value Equipment
Costs & Implementation

Rolling Straight Edge	1970	$ 2,500. ±
Mays Ride Meter Transmitter & Recorder Set	1978	$ 1,550.
Odometer (DMI)	1980	$ 630.
1st. project with an incentive rideability specification	1981	-
Mays Ride Meter Trailer, Trans. & Recorder	1982	$ 5,250.
Pave. Cond. Redorder (PCR)	1982	$ 5,800.
California Profilograph	1982	N.C.
1st disincentive assessed	1986	-
Accelerometer Delta Shear Set	1987	$ 550.
Sound Level Meter (SLM)		$ 4,400.
Calibration Exciter		$ 1,160.
Printer		$ 250.
Interface, cables, & misc.		$ 1,340.

APPENDIX C

TRAFFIC CONTROL FOR PAVEMENT EVALUATION TESTING AND ADJACENT TO ROADWAYS

A. SIGN LAYOUTS

Traffic control for pavement management survey operations shall be done in accordance with the Manual on Uniform Traffic Control Devices. The following are the signing and control devices deemed necessary at our work sites:

1. For pavement drilling work sites where short length one-way traffic control is normal. (See Figure 1 for traffic control layout.)

   First Sign -- EQUIPMENT IN ROAD
   Second Sign -- BE PREPARED TO STOP
   Optional -- NEXT 3 MILES and FLAGGER AHEAD
   Flagger - one or two as required

2. For Road-Rater work sites where stop and pass traffic is generated. (See Figure 2 for traffic control layout.)

   First Sign -- EQUIPMENT IN ROAD
   Second Sign -- BE PREPARED TO STOP
   Optional -- NEXT 3 MILES
   Flagger - vehicle - one or two as required

3. For Ride Meter work sites, we do not control traffic. Testing is done at near design speed. However, intersections will be flagged as may be desirable.

All equipment and supplies needed for traffic control are available from WDFD Purchasing, Property and Supply Unit. Equipment and supplies meet MUTCD specifications.

B. FLAGGERS

Requirements for flaggers vary with the states we work in. Flaggers in all states, however, must meet the requirements set forth in the Manual on Uniform Traffic Control Devices, Part E, entitled "Control of Traffic Through Work Areas."

In Washington and Idaho, flaggers must be certified by the State. In Idaho contact Idaho State Department of Highways; in Washington contact Washington State Department of Labor and Industries, Safety and Health Division.

Supervisors should arrange for this training as soon as possible after establishing the project crew.

C. STANDARD TRAFFIC CONTROL KIT

The following set of equipment will handle traffic control during daytime operations and provide extra equipment for the period while signs are being moved so that the drill need never be unsigned.

Quantity	Item	Catalog No.
4	Vest, Safety	1450
4	Flag, Warning, 16" x 16"	1584
2	Sign, STOP/SLOW, paddle	1577
3	Sign, BE PREPARED TO STOP	1582
3	Sign, FLAGGER	1580
2	Sign, EQUIPMENT IN ROAD	
2	Sign, NEXT 3 MILES	
6	Rack, sign	1572

Figure 1.

TYPICAL SIGNING FOR NORMAL ONE-WAY TRAFFIC, PAVEMENT CORING SITE

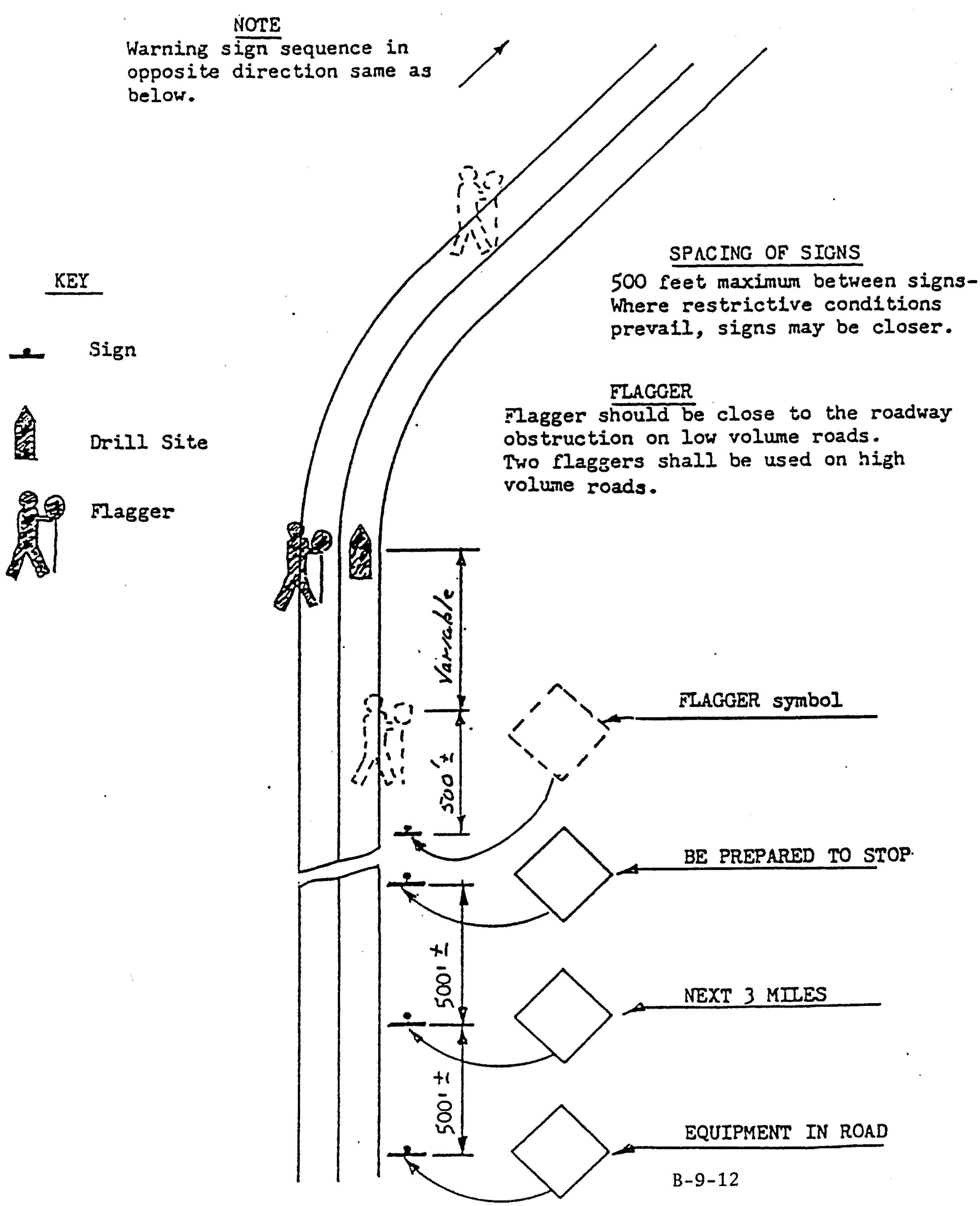
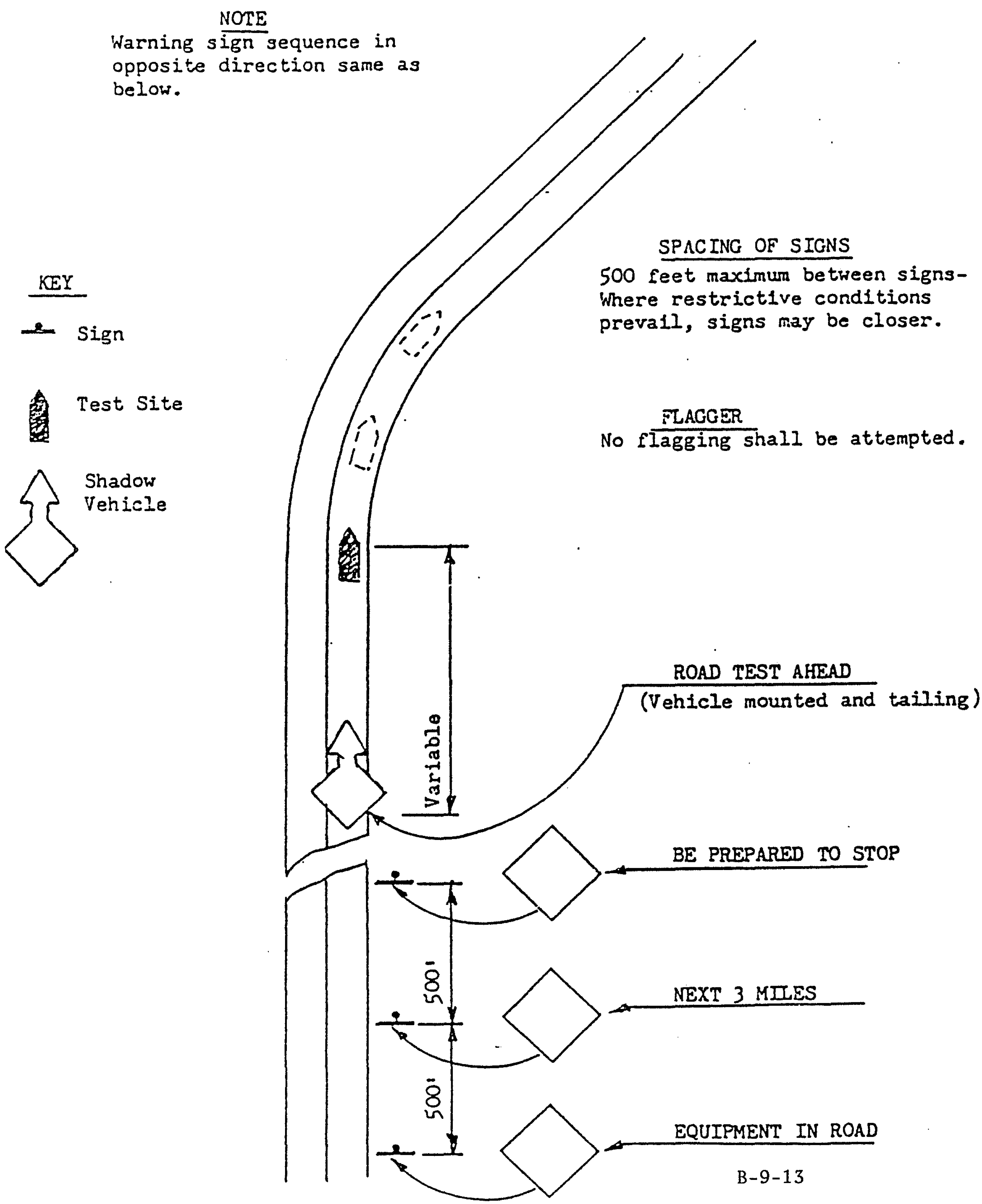


Figure 2.

TYPICAL SIGNING FOR NORMAL ROAD-RATER OPERATION



FEATURE	ROLLING STRAIGHT EDGE	PROFILOGRAPH	MAYS RIDE METER	ACCELEROMETER
Vertical Mechanism	Single wheel suspension, machanical with audible & visual signals - manual recognition & recording	Tricycle suspension, machanical with automatic recognition & graphical recording	Axle suspension , machanically driven optical sensors with electronic transfer & recording	Axle mounted accelerometer, electronic sensor, transfer, and recording
Distance Mechanism	Survey chain	Distance wheel, fully engaged & automaticly recorder	Gear driven sensor, with electronic adjustment & automaticaly recorder	Time is the method, distance can only be estimated.
Recording Mechanism	Manual recording in note form, arbitrary evaluation & engineering judgement - office time required	Mechanically recorded in graph form, arbitrary evaluation & engineering judgement - office time required	ADP with final value printed on the spot	ADP with peak, max, min, and average thru a sound level meter is printed by a separate instrument. Test time is recorded, not distance
Traffic Control	Signing & 3 to 5 flaggers	Signing & 3 to 5 flaggers	none	None
Test Time	100 minutes per mile (4 track miles), plus flagging & evaluation (7 man hours))	132 minutes per mile (4 track miles), plus flagging & evaluation (9 man hours))	30 minutes per mile (6 lane miles), including final computation ((1/2 man hour))	30 minutes per mile (6 lane miles), including final measurement. (1/2 man hour)
Standard Data Developed	Deviations, plus/minus 1/8" from a variable 10 ft. mean (longitudinal/transverse) are identified & marked on the pavement. No rating is compiled	Scallops (high & low points) in excess of 2/10" from a variable 25 ft. mean (long.) are arbitrarily determined in the office, can be later identified on the pavement Profile Index (PrI) = $\frac{1}{\text{Miles Tested}} \times \frac{\text{Counts*}}{10}$ (* 1/10" as scaled)	Axle-Body response in 1/10" steps are accumulated - sub-totals per 8th. available Ride Rating = MRM Inchs = $\frac{\text{Counts*}}{\text{Miles Tested}} \div 64$ (* 1/10 movement & return = 2 Counts)	Axle response in decibels. Subtotals not availble - MRS can probably be equated MRM Inches. Very limited experience to date (4months)

PORTABLE UNIVERSAL ROUGHNESS DEVICE (PURD)
ONTARIO, CANADA

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

USE OF THE PURD
IN THE CITY OF PHOENIX

Submitted by

Bruce C. Varker
Civil Engineer II

The City of Phoenix street system consists of approximately 3,500 miles, of which approximately 900 miles are major (arterials) and collectors. About 99% of the system is flexible pavement varying from "oil cake" to full depth asphaltic concrete. Not quite 50% of the system is younger than twenty years. Soil and climatic conditions are favorable to long life pavements.

Surface treatments (seal coats), crack sealing and thin overlays had proven to be very effective maintenance methods. It is estimated that as much as 50% of major and collector street system could be substandard in terms of its load carrying and/or traffic carrying capacity. A lesser percentage, but still a good third of the local street system may be substandard or have passed its expected life period.

Roughness caused by loading, utility cuts, base failure and settling, valve boxes and manholes is a system-wide problem. Utility lines are relatively shallow. Cracking, ravelling, bleeding, rutting, and slippery surface are the prevalent surface distresses.

The Street Maintenance Division of Streets and Traffic Department formerly developed its annual seal coating program by conducting a visual survey of streets and selected the ones needing maintenance the most. The system relied on historical records of maintenance and the judgment of experienced individuals. The object was to maintain the network in a regular cycle, the length of which was the life expectancy of the treatment applied.

This "Band-Aid" approach was extremely subjective and gave no consideration to whether the treatment selected would be cost effective or not. The areas that screamed the most usually received treatment while other neighborhoods were totally ignored.

The City of Phoenix entered into a contract to develop a Pavement Management System and decided to use automated data collection. The decision was made to purchase a Portable Universal Roughness Device (PURD) unit from Highway Products International (HPI) in Paris, Ontario, Canada. The City further decided to install the PURD in a van rather than use the trailer-mounted unit.

The PURD system measures roughness or ride using an axle-mounted accelerometer. The PURD also uses microprocessor-based Pavement Condition Rating Keyboards for entry of observed Pavement Distress type, severity and extent measurements. The system also incorporates a Distance Measuring Instrument (DMI) to accurately measure all surveyed sections and record the locations of distresses or other inventoried items.

The unit was purchased for an initial cost of $34,200 and installed in the City's Chevrolet Sports Van in Phoenix. The installation testing and calibration was completed in two days and training began. The initial specifications did not have the video screen (CRT) to view data. Condition data was displayed by an LCD window on the master keyboard. It was soon apparent how advantageous it would be to view data as collected and have the ability to stop and verify the data after running the section. In February 1986, we ordered the video screen upgrade for $2,500 and have seen the advantages of having it every day.

HPI has a Pavement Management System called PEP (Pavement Expenditure Planning), however, the City of Phoenix had a custom Pavement Management Program designed by Pavement Management Systems, Inc. of Lakewood, Colorado, so we did not purchase the software. The PURD software is easy to use and very "user friendly."

The greatest maintenance costs are for yearly replacement of the shocks and tires, along with front-end alignment at the start of each testing year. The equipment is very reliable and the only major problem has been with the tape drive mechanism from an outside source.

For safety in traffic, we have a flashing arrow board on the rear of the van and yellow strobe lights on the front. This would seem to be a minimum for driving in traffic volumes of up to 60,000 AADT in Phoenix at 15 to 20 mph.

Daily start-up procedure is to run a computer-generated time drive during which the tire pressure is checked. Then a distance measured control street is driven to check the D.M.I. readout. The third check is to drive the roughness control measured street and check against the previous averages. If a variance of more than $\pm$ 20 raw data number occurs, the test section is run again. High temperatures seem to adversely affect the reliability of the raw ride numbers, so in Phoenix we test major and collector streets from about November through March when ambient temperatures are below 90^{o} F, and have experienced very reliable results. The manufacturer reports a correction for this, but we have not had to do this.

The only disadvantages in an urban environment is driving at collector speeds of 15-20 mph and having a keyboard on the driver's lap. This could be a potential safety hazard, but no problems have been encountered to date. Mechanically, the tape drive for the casettes has been the only problem, but the new version has a floppy disk drive and this has been solved. What electronic problems we have experienced have been resolved immediately by the manufacturer. HPI's response and help has been excellent in the two and one-half years we have dealt with them. Their support of the City's unit is almost unheard of in the manufacturing world today.

Excessive Phoenix summer temperature originally did affect the DMI shaft encoder and its housing was relocated by the manufacturer to the air conditioned interior of the van without further problems encountered.

Reliability and repeatability have been checked and verified many times. As long as tires and shocks are changed yearly, the output from the unit should be very consistent.

I have experienced staff training to use the unit twice. The first time was the initial training of the two technicians who drive and rate. The last time was training a replacement for one of the original technicians. If distress recognition has been achieved, the ability to use the equipment should not take more than 3-5 days. Distress recognition is a "must" prior to learning the system because instantaneous assessment must be made and input on the keyboard during the 60 foot sections.

Inside the van are two distress keyboards for the driver and rater, and a master keyboard, the computer and tape drive. The rating keyboards have eight special events keys that could be used for any inventory purpose such as bus stops, catch basins, valves, manholes, signs, etc. The first rater (driver) keyboard, for flexible pavement, is set up to record pavement type; patching; curb and gutter and drainage, etc.; rippling, shoving; ravelling, streaking; flushing, bleeding; distortion; excessive crown; and four special events keys that commonly are intersections, railroad crossings, bridges and culverts but could be changed to suit. Distresses are input for severity and area.

Rater two (passenger) keyboard, for flexible pavement, records pavement edge cracking, alligator cracking, pot holes, map cracking (block), longitudinal and meandering cracking, transverse cracking and wheel track rutting. The special events keys are manhole cracking and/or shrinkage, catch basin, service patching and a blank one.

Data collecting in Phoenix averages about 20 curb miles per day. We are capable of getting much more, but processing time in the office for the pavement management data limits the time spent in the van. In addition, traffic volumes increase dramatically after approximately 11:30 a.m., especially in the cooler months with the winter visitors out and about on the streets. Travel time and data collection averages about six miles of street per hour on major and collectors. Residential streets would probably not be as productive.

The City of Phoenix uses the PURD unit to condition survey the entire major and collector street system each year. We hope to include an additional half of the residential street system each year also. In addition, when a newly constructed street appears to be rough, the PURD has tested it for roughness along with the walking profileometer. Special tests have also been run along haul routes before and after extensive excavations for high-rise projects. The condition before and after hauling, along with deflection data help the City assess the damages caused by the contractor.

Acceptance of the new technology utilized by the PURD has been slow, but the advantages of automated data collection and uses for roughness data are being recognized and put to use throughout the City. The manufacturer has recently announced the availability of an equipment upgrade to allow the collection of longitudinal profile roughness. With this form of the PURD, an agency could verify construction acceptance as well as ride and data collection.

DYNATEST 5000
MISSISSIPPI HIGHWAY DEPARTMENT

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

USE OF THE DYNATEST 5000 ROUGHNESS AND DISTRESS MEASUREMENT TEST SYSTEM IN MISSISSIPPI

By

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For presentation at the Pavement Profile Measurement Seminar, FHWA Demonstration Project No. 72 Open House, Ft. Collins, Colorado

October 5-8, 1987

USE OF THE DYNATEST 5000 ROUGHNESS AND DISTRESS MEASUREMENT TEST SYSTEM IN MISSISSIPPI

Introduction

The Mississippi State Highway Department (MSHD) is currently involved in Phase One of a proposed 3-phase effort to develop and implement a formal, comprehensive pavement management system (PMS) for our state maintained system. This first phase is the development of a pavement management information system (PMIS) for one of our six districts. One of the objectives of PMIS is to develop a pavement condition rating system where roughness and distress data can be combined into a single number. After considerable study we selected the Dynatest 5000 Roughness and Distress Measurement (RDM) Test System. This report documents our experience with the Dynatest 5000 RDM.

Description of Equipment

Principles of Operation

The RDM is a response-type road roughness measuring system (RTRRMS) which uses an ultra precision accelerometer (UPA) to generate the statistic root-mean-square vertical acceleration (RMSVA). The RMSVA statistic is not a measure of vertical acceleration but is equivalent to the mid-chord elevation that would be obtained from a rolling straightedge. Simply put the RMSVA is the RMS value of a mid-chord deviation that would be obtained from a 3-point moving straightedge.(1) Since RMSVA is vehicle dependent, a mechanism is needed to correlate this measure of vehicle response to an accepted road roughness statistic. The RDM uses slope variance (SV) as this statistic. An expression relating SV to RMSVA is as follows:

$$SV = C_v \left[\frac{RMSVA}{V^A}\right]^B \qquad (1)$$

where C_v = vehicle constant

V = speed of the vehicle (km/h)

A = average slope of the log RMSVA vs log V regression line of the calibration sections

B = a constant based on empirical results.

Once RMSVA is converted into SV, an expression developed at the AASHO Road Test relates SV to PSI as follows

$$PSI = 5.0 - 1.9 \log (1 + SV) \qquad (2)$$

where PSI = Present Serviceability Index

Vehicle constants are derived for three different operating speeds: 30 mph,45 mph and 55 mph. The RDM software will calculate not only the PSI at 45 mph but also the PSR (Present Serviceability Rating) at any other speed desired by the user. This capability is useful when it is desirable to find PSR at speeds different from the measured ones.

Components of RDM System

The RDM has two main functions; namely, collecting pavement roughness data for computing PSR and collecting pavement distress data through an 8-channel event recorder for user defined visually observed distresses. System components are as follows:

1. A digital distance encoder provides pulses for distance and speed computation.

2. A processor and microcomputer for real-time computation, plotting, printing and magnetic storage of all data.

3. A chassis mounted accelerometer (UPA) described earlier.

4. Hand-held event and start/stop keypads.

5. A dual beam calibration assembly (4-point support, 2 in each wheel path) where the UPA acts as a high precision inclinometer.

6. Software to accomplish various tasks. A more detailed description of the software will be given later.

Calibration Procedure

As described earlier, the RDM computes PSR from the RMSVA of the vehicle through transforms relating SV, RMSVA and PSR (PSI). The data for calculating RMSVA is provided by the UPA which leaves only the measurement of SV. The dual beam calibration assembly with the UPA attached generates the data needed to calculate SV.

The calibration procedure involves, first, the selection of calibration sections. Due to the complexity of roughness, several calibration sections must be selected covering a range of roughness from approximately 2.0 to approximately 3.5. As a minimum at least 2 sections for each of 3 PSR levels are needed, with the 3 levels being (approximately) 2.0, 3.0 and 3.5. The calibration sections are each 200 meters long.

After the calibration sections have been identified, the dual beam calibration assembly is used to determine the average SV for the sections. This is accomplished by mounting the UPA on the calibration beam where it acts as an inclinometer. The calibration beam has 4 support points (2 in each wheel path). The support points in each wheel path are 0.25 meter apart. The calibration-beam assembly is suspended from a 2-wheel cart which allows easy, one-person maneuvering of the assembly through the 200 meter calibration section in 0.25-meter increments. The calibration assembly is attached to the processor and microcomputer in the vehicle by a long umbilical cord. This process of measuring the SV of a calibration section is referred to as "profiling". Once the SV for the calibration section is established, the UPA is again mounted on the vehicle and the vehicle is driven over the section at speeds from 50 km/h to 90 km/h in 10 km/h increments. Three runs are made over the section at each speed. After the vehicle has been driven over all sections at the various speeds, RDM system software processes the data to determine the vehicle constant for use in equation 1. With the calibration procedure now complete, the RDM is ready to roughness measurements.

Roughness Surveys

Once the vehicle calibration constant has been determined, roughness measurements are straight forward. The roadway to be tested is traversed at the proper speed (normally 45 mph) while the RDM gathers and stores the data. In its present configuration, RMSVA data is averaged for each 0.04 mile and converted to PSR. Data is stored on magnetic media for further analysis in the office. Field data can be monitored during the roughness survey to insure proper operation of the system. It is advisable to run the RDM across a section of known SV periodically to insure that the system is operating properly.

Distress Survey

Distress surveys are conducted by driving over the roadway at a slow speed (normally 10-20 mph) and recording visually observed distresses on the microcomputer through the 8-channel hand-held event keypad. Eight user-defined distresses are available with three levels of severity/extent.

Software

The microcomputer included with our RDM System is a Hewlett-Packard HP 85B. The software programs and field data are stored on microcassettes. The field program is composed of 5 main parts:

1. Roughness (PSR)
2. Distress (DR)
3. Distance Calibration (DCAL)
4. PSR Calibration (PCAL)
5. Profiling (PRF)

- The Roughness program accepts pulses from the UPA and distance encoder and calculates PSR for roadway segments. Values are printed on paper tape and stored on microcassette.

- The Distress program accepts pulses from the 8-channel keypad and distance encoder and stores this data on microcassette. A paper tape record is also produced.

- The Distance Calibration program provides a method to calibrate the distance encoder over a measured mile.

- The PSR calibration program is very similar to the Roughness program as it accepts pulses from the UPA and distance encoder and stores values for RMSVA for the calibration sections at the different speeds.

- The Profiling program accept signals from the UPA while mounted on the calibration assembly. This program stores SV values for the calibration sections for further use in determining the vehicle constant.

A separate program is called PSR calculation (PSRCAL). This program imports SV values from the PRF program and RMSVA values from the PCAL program and performs a regression analysis to determine the vehicle constant.

Additional programs are included with the RDM that produce graphics and summary statistics for reports. Examples of the graphics are shown in Figures 1 and 2. Roughness (PSR) and distress data (user defined) can be extracted for any given roadway segment for whatever purposes an agency desires.

Pavement Condition Parameters

Roughness

Roughness in terms of PSR is the ride output. The PSR values are computed each 0.04 mile and can be averaged over longer segments as desired. Identification of data is done by route identification and milepost.

Distress

Distress data is expressed in categories that are user defined with an upper limit of eight distresses. Each distress is represented by one of the keys on the hand-held keypad. Extent and severity of each distress is entered by making one, two or three pushes of the respective key. Figure 3 shows a 3 x 3 matrix which gives the three-level condition rating of good, fair or poor for both extent and severity. The combinations of extent and severity as shown determine the number of times a distress key is pushed. Good, fair or poor are denoted by 1, 2 or 3 pushes, respectively. Roadway segment length used for distress surveys is 0.02 mile. Identification of data is done by route identification and milepost.

Acquisition Costs of Equipment

The MSHD made the decision to lease the RDM for a minimum of 2 years, (maximum 4 years). This decision was made for several reasons, chiefly the rapid change in state-of-the-art of such equipment. The annual lease cost is $10,500 which includes insurance. Delivery, installation in a MSHD vehicle and training in calibration and operation cost $3100. These costs covered all hardware and software. The MSHD is developing some simple programs in-house to further analyze the RDM data, for which no cost figures are available.

Additional information on any available options should be addressed to:

Dynatest Consulting, Inc.
P. O. Box 71
Ojai, California 93023
(805) 646-2230

Operating Cost

Average costs to operate and maintain the equipment have been computed and include labor (plus additive), vehicle rental and miscellaneous supplies for the field data collection. The cost of roughness surveys is approximately $4.00/mile while the distress survey cost is approximately $8.70/mile. The higher cost for distress surveys results from the lowered productivity and the need for a backup vehicle to control traffic.

General Observations on Equipment Use

Operating Requirements

Operation of the RDM for roughness surveys is not complex. Probably the most arduous task is marking the end points of highway sections. Our approach was to mark the end points with florescence paint before beginning the survey. An annoying part of the survey was the time delay due to opening and closing files on the on-board microcomputer. We divided our system into homogeneous sections with an average length of 3.5 miles; consequently, we spent about one-third of the time opening and closing files, which is slow on the HP-85B. This problem could be reduced substantially by switching to a faster microcomputer.

Distress surveys involved the same tasks as for roughness surveys plus a backup vehicle towing a trailer-mounted message board for traffic control due to the slow speed of the survey vehicle.

Personnel Needs

Once the system operators are trained, two persons are adequate for system operation. Roughness surveys could be done with one person but the productivity would decline.

Alternate Uses of the RDM Within the MSHD

Equipment installation. calibration and performance of the roughness and distress surveys for the 1850 mile road network in our District Two required approximately five months. The RDM was also used by our planning division to run roughness surveys on the HPMS sample sections, which required about four months. The remainder of the year the RDM was used by our research division to conduct roughness and distress surveys on research projects. Other possible uses for the RDM that have been mentioned, but not yet persued are:

1. Roughness survey (inventory) on state system

2. Acceptance criteria for new pavements and overlays

Limitations and Disadvantages

The most annoying disadvantage we have noticed concerns the microcomputer. A faster microcomputer would improve productivity. Another drawback is the additional step required to transfer the data from microcassette to disk storage. Also, some of the software subprograms have proven cumbersome. In fairness, however, that statement would be true for the majority of software we use.

The obvious limitation of the RDM in conducting distress surveys is the dependence on the subjective opinion of the operator. After several hours of distress surveying the operator may have trouble adhering to a consistent rating standard.

Manufacturer Support

We have been well pleased with the spirit, attitude and abilities of the manufacturer in problem resolution.

Equipment Durability, Reliability and Repeatability

Durability, reliability and repeatability of the equipment has been excellent. Lost time due to these factors is very insignificant.

Effects of Various Vehicle Loadings

No efforts have been made by MSHD to gauge the effects of different vehicle loadings. We have adopted a standard vehicle loading for roughness measurements and adhere to it.

Effect of Changes in Vehicle Characteristics

No detailed study has been made to determine how changes in vehicle characteristics affect the accuracy and/or repeatability of measurements. We have observed excellent repeatability of roughness measurements over the two month period spent gathering roughness data in District Two.

Training

Estimated training time for calibration, roughness and distress surveys and software usage is 40 hours per person.

Average Costs for Data Collection, Analysis and Reporting

The costs for data collection were given earlier. Costs for data analysis and reporting are not currently available.

Equipment Productivity

Average productivity for roughness and distress surveys are 80 miles and 50 miles, respectively, for an 8-hour day. Each day's activities began and ended at a central point in the district; consequently, nonproductive travel time is a significant part of the daily schedule.

Application of the RDM in Mississippi

To date, the MSHD has used the RDM for network level condition surveys in one district, roughness inventory on the statewide HPMS sample sections and project level condition surveys on a limited number of research projects.

Economic Considerations

Since the major work with the RDM is a new venture for us, we have no basis for economic comparisons. The roughness inventory of the HPMS sample sections will provide a basis for cost comparison. However, that work is incomplete at this time and cost figures are not yet available.

Equipment Modifications

No modifications have been made to the equipment. Slight changes have been made to the software. A separate distance measuring instrument using wheel-mounted sensors has been added to the vehicle to help locate roadway sections.

REFERENCES

1. Sayers, W. S. et al, "The International Road Roughness Experiment", World Bank Technical Paper No. 45, The World Bank, Washington, D. C., 1986.

2. "Pavement Distress Manual" Report No. 1, Pavement Management Information System, Department of Civil Engineering, The University of Mississippi, September, 1986.

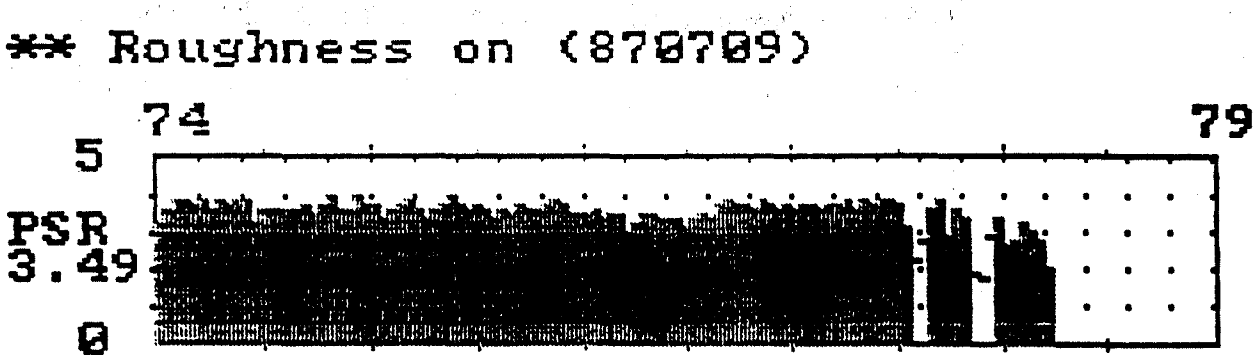


Figure 1. Sample output for roughness data

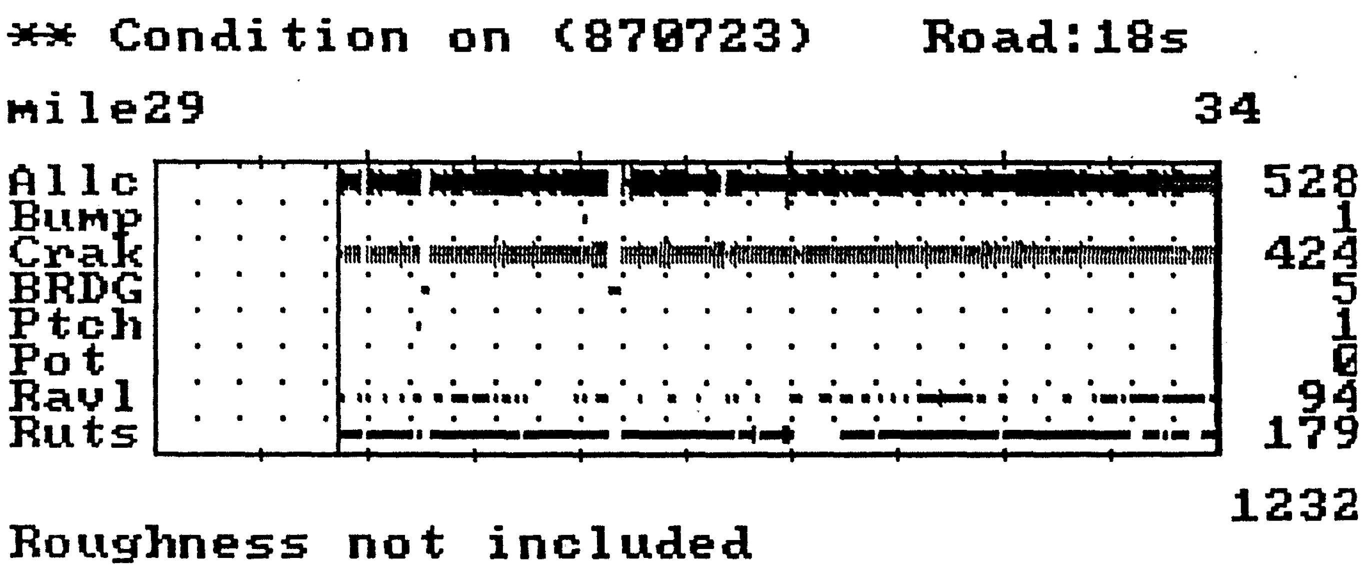


Figure 2. Sample output for distress data

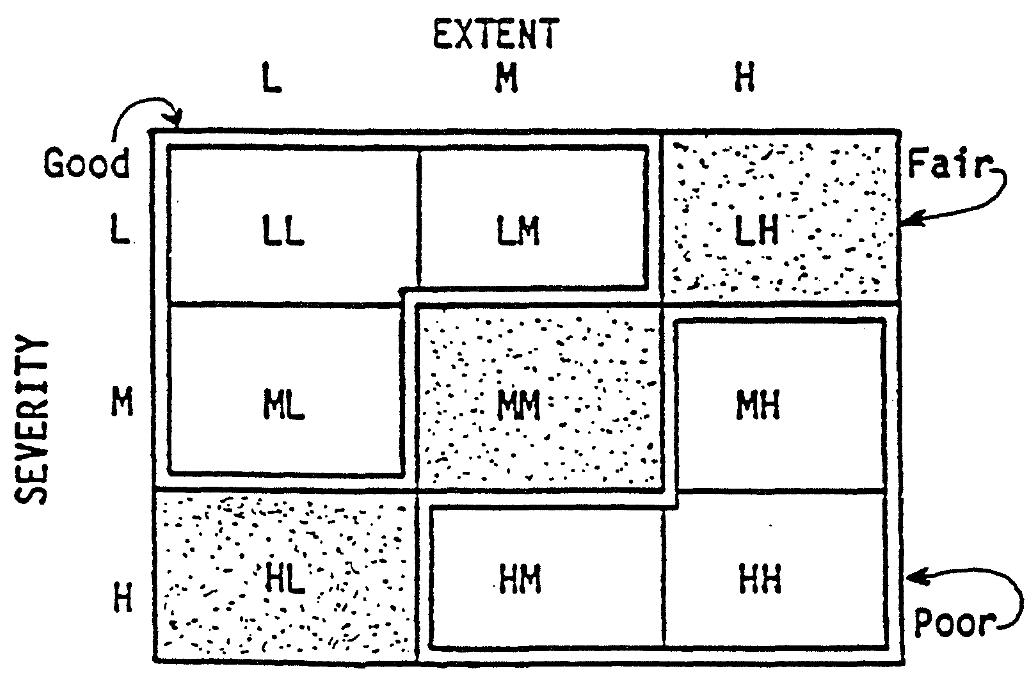


Figure 3 Three-level Condition Rating Based on Severity and Extent (Reference 2)

SELF-CALIBRATING ROUGHNESS DEVICE (SIometer)
TEXAS HIGHWAY DEPARTMENT

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

Walker Roughness Device

Even though the profilometer produces accurate measurements, it is rather expensive to obtain and operate. Because of this the Mays Ride Meter and, more recently, the WRD (also known as the SIometer) are currently being used in Texas for roughness measurements. The WRD provides an estimate of the road profile. From these measurements the slope variance of the predicted profile for a four inch base length is then calculated. The WRD uses this value, which has been correlated to PSI, to determine the serviceability index (SI) of the road.

The WRD consists of three components: a sensor unit, main control module and, optionally, a computer for storing the results. The device uses an accelerometer as its primary sensor. Before using the device for measurements it is driven over a short road section which is used by the WRD to perform a statistical model of the vehicle's response. The model parameters determined in this dynamic calibration procedure is then later used during the measuring process for removing the vehicle's characteristics. The process of identifying and modeling the current or dynamic vehicle characteristics is referred to as the self-calibrating process. Each of the major components of the WRD is briefly discussed below.

The accelerometer, or sensor, is housed in a small case which is weighted down and mounted vertically inside the trunk of the vehicle. Similar to the SDP, the accelerometer measures the vertical acceleration of the vehicle. The signal from the accelerometer is transmitted to the main control module where it is digitized and processed. Unlike the SDP, however, this signal is then used in a statistical process to remove the effects of the vehicle's suspension system, thus not requiring the road following wheels or non-contact probes for body-road displacement.

The main control module contains two Motorola 68000 microprocessors working in parallel to accomplish the necessary real-time computing. Additional hardware includes an analog-to-digital converter, power supply, ROM and RAM chips, etc. The program for analysis of the profile is stored in ROM in this module. The WRD is portable and can be installed in a vehicle within minutes.

The WRD provides SI, an unscaled predicted slope variance, and the measurement speed on a LCD display. Also available soon will be the estimated profile. An optional storage unit such as a Zenith lap-top computer can be used for interfacing with the WRD. A communication program in the Zenith and WRD provides interface between the control module and the PC. This program operates primarily in two modes: (1) terminal mode for debugging purpose, and (2) real-time mode for data collection. Additionally a voice box, which is made up of a speech synthesizer and speaker, is connected to the Zenith. It informs the operator of the status of the real-time operation using a series of English words. This eases the work of the operator, who can also be the driver of the vehicle.

The WRD supports TSDHPT software for communications with Zenith data systems 171 and 181 portable computers. This information is used as part of the Pavement Evaluation System survey to provide data concerning the condition of pavements for ride quality. The data can be used by itself or in combination with environmental, visual, and traffic data to assist in describing the overall condition of the State Highway system. the PES data can also be used to make general estimates of statewide pavement rehabilitation funding needs.

The WRD outputs a SI serviceability index of roughness ranging from 0.0 (roughest) to 5.0 (smoothest) to the portable computer and is stored in a form compatible to the Maintenance Management System used by the Department. See Figure 1. SI values are collected for every .2 mile and formated in one mile data segments with any comments.

```
MMSS11402000R102387290443A246IH0031 000+00002+0001$$$$$$$$$$$$$
MMSS200133    27    31    25    38 3
MMSS200228    29 4  36    32    29
```

Figure 1

The following is an explanation of Figure 1.

FIRST LINE:
MMS - SYSTEM ID
S1 - CARD ID
14 - DISTRICT NO.
02000 - USER LENGTH ID
R - LANE
102387 - DATE
290443A - VEHICLE ID
246 - COUNTY
IH0031 - HIGHWAY NO.
000+00 - BEGINNING MILE POST
002+00 - ENDING MILE POST
01 - PAVEMENT TYPE
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$ - COMMENTS/NOTES

SECOND LINE:
MMS - SYSTEM ID
S2 - CARD ID
001 - CARD SEQUENCE ID
33 - SI OF 3.3
27 - SI OF 2.7
31 - SI OF 3.1
25 - SI OF 2.5
38 - SI OF 3.8
3 - COMMENT CODE CORRESPONDING TO THE PREVIOUS SECTION

THIRD LINE:
MMS - SYSTEM ID
S2 - CARD ID
002 - CARD SEQUENCE ID
28 - SI OF 2.8
29 - SI OF 2.9
4 - COMMENT CODE CORRESPONDING TO THE PREVIOUS SECTION
36 - SI OF 3.6
32 - SI OF 3.2
29 - SI OF 2.9

The acquisition cost of the WRD and computer is \$20,000.00. An additional \$10,000.00 to \$12,000.00 is needed for the vehicle. Since the vehicle does not have to tow a unit the average cost to operate and maintain the equipment is limited to the operational costs of the vehicle. The WRD unit is solid state circuitry and requires no maintenance. The computer will require some maintenance as required by the manufacturer.

The WRD operates at speeds of 20 to 50 mph and requires no traffic control, and can be operated by one person, however, some conditions may require an observer. When conditions permit an average of 300 miles/day can be evaluated on highways where a speed of 50 mph can be maintained. The slower speeds are useful under metropolitan conditions.

Since the unit is portable it can be easilly installed and ride data can be quickly obtained in a usable form, and can be removed for office storage. At the present SI is the only roughness rating unit output, a profile or RMSV is desireable in some correlations.

Since the WRD has a selfcalibrating feature any vehicle characteristic changes can be compensated for by recalibrating under the new changes.

Personell training necessary for use of the WRD is minimal, for the computer related training for some will be required. Inventory familiarization for the PES system is necessary for quality data collection.

The WRD, in general, is a compact device which can be installed and operated in virtually any vehicle. It is simple to use and can be operated by only one person. Its cost is inexpensive compared to the SDP's and is not much more than the cost of the MRM with trailer.

AUTOMATIC ROAD ANALYZER (ARAN III)
TEXAS HIGHWAY DEPARTMENT

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

AUTOMATIC ROAD ANALYZER

ARAN

The Texas State Department of Highways and Public Transportation has recently purchased an ARAN to collect roadway data in high traffic urban areas. The Department is in the process of using the ARAN to collect the visual distress and ride data for the Pavement Evaluation System. This system is used to report the overall condition of the state-maintained highway system.

In the past, multiple techniques were needed to determine the condition of urban pavement surfaces. First it was necessary to visually survey the pavement surface and then record these observations in an orderly and consistent manner. This required raters to travel along the side of busy roadways -- stopping at least every 1/2 mile. At each stop, the raters walked 100 feet in each direction observing and categorizing the distress types viable. Rutting was then measured at three locations within the 200 feet. Then, a separate pass is made to collect ride data with either the Mays-Ride-Meter or the Walker Roughness Device.

The new ARAN is capable of collecting both the visual distress and ride quality while traveling 50 mph. Therefore, the Department experiences a safer, more efficient method of data collection ... a higher quality of data ... and a pictorial documentation that can be referenced and re-evaluated at a later date. And the ARAN's systems have the capability of producing data at various levels of detail.

The videolog/data system permits the reduction of pavement data at any time subsequent to acquisition. The data processing system enables the synchronization of video with the other data acquisition systems. The simultaneous collection of both visual and quantitative measurements is a valuable roadway analysis tool.

The collection of PES data utilizes several of the ARAN systems. The ARAN video system includes two cameras to capture roadway image. The front camera is color and is used for orientation and identification of distress areas. The second camera is a black and white, high speed shuttered camera and is located at the rear of the vehicle and is aimed almost perpendicular to the pavement. It is the rear camera which provides the resolution necessary for the identification of pavement cracking while traveling at 50 mph.

An array of sonar sensors are located at the bottom of the bar extended in the front of the vehicle. These sensors can measure rutting with an accuracy of 0.1".

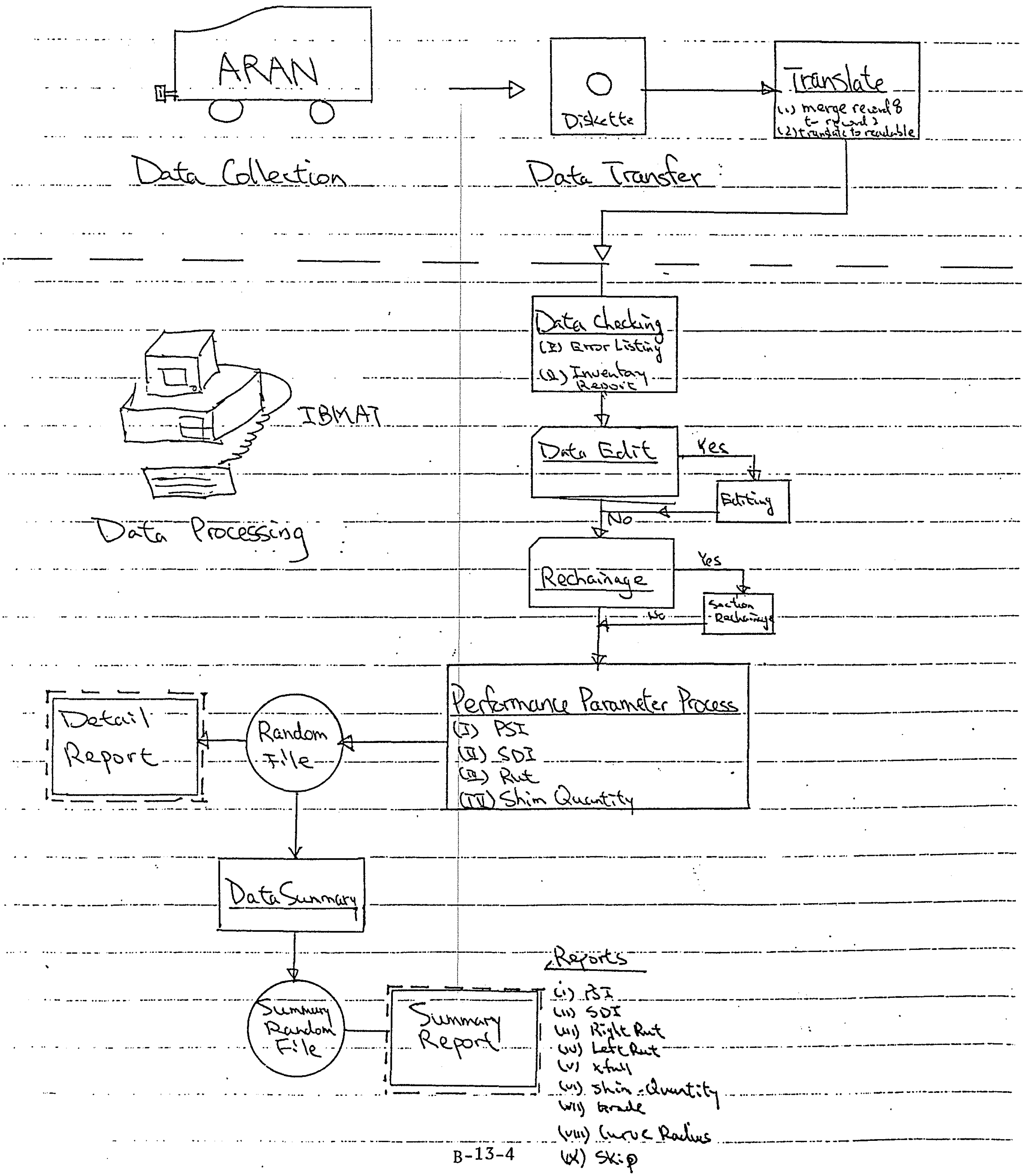
A body mounted accelerometer and an axle mounted accelerometer are used to provide an evaluation of pavement roughness at speeds of 30 to 50 mph.

The ARAN has become such a valuable tool in Texas' urban areas that the Department is planning to phase out the manual evaluation throughout the rest of the state once an optical disk storage system and a laser crack detection system have been integrated with the existing ARAN systems.

The ability of ARAN to produce pavement plans and profile data with the accuracy needed to develop plans for pavement reconstruction in Texas has not yet been fully tested.

Also, studies are in progress to determine the feasibility of using the ARAN to collect the data needed for the Federal Highway Administration's Highway Performance Monitoring System.

It is only with innovative automation equipment like the Automatic Road Analyzer that the Department will be able to meet the ever increasing demands being placed on the Texas Highway systems.



ARAN
Data Collection
Diskette
Translate
(1) merge record 8 & record 3
(2) translate to readable
Data Transfer
IBM AT
Data Processing
Data Checking
(I) Error Listing
(II) Inventory Report
Data Edit
Yes
Editing
No
Rechainage
Yes
Section Rechainage
No
Performance Parameter Process
(I) PSI
(II) SDI
(III) Rut
(IV) Shim Quantity
Random File
Detail Report
Data Summary
Summary Random File
Summary Report
Reports
(i) PSI
(ii) SDI
(iii) Right Rut
(iv) Left Rut
(v) x fall
(vi) Shim Quantity
(vii) Grade
(viii) Curve Radius
(ix) Skip

RATER #2

Flexible Pavement

KEYS

A	Pavement edge cracking
B	Alligator cracking
C	Pot-holes
D	Map cracking (Block)
E	Longitudinal and Meandering cracking
F	Transverse cracking
G	Wheel track rutting
	Special Event Keys
K	Manhole cracking and/or sinkage
L	Catch Basin
M	Service Patching
N	Not used at present

1,050

Note: Special Event Keys shown are commonly used, but can be changed to suit customer needs.

Appendix B

<u>AUTOMATIC ROAD ANALIZER®</u>
MOBILE
DATA ACQUISITION
VEHICLE

HIGHWAY PRODUCTS INTERNATIONAL INC.

AUTOMATIC ROAD ANALYZER - ARAN®

The ARAN® design is firmly based on almost two decades of practical experience in the highway construction and maintenance fields. Backed, as well, by some eight years of intense development and testing, the ARAN® is soundly engineered to provide pavement engineers with state-of-the-art tools to do a first-rate job.

The ARAN® is a MOBILE DATA ACQUISITION VEHICLE capable of collecting and recording large quantities of roadway data quickly and economically. Truly unique in its wide ranging capabilities, ARAN® applications include both network inventory and project pre-engineering analysis.

It is the purpose of this booklet to introduce the ARAN® , its subsystems and unique functions and to indicate how they can help you achieve maximum results from your pavement expenditures. Further details are published in engineering technical papers and product brochures some of which are referenced.

We look forward to the opportunity to discuss with you how the ARAN® can fit into your pavement management activities.

ARAN® DIVERSIFIED APPLICATIONS

TYPE OF SURVEY	LEVEL OF ACTIVITY	
	NETWORK	PROJECT
• Roughness	+	
• Longitudinal Profile	+	
• Surface Distress	+	
• Rut Depth	+	+
• Grade	+	+
• Crossfall	+	+
• Transverse Profile	+	+
• Curve Radius	+	+
• Right-of-way Videologging	+	
• Pavement Condition Rating Videologging	+	
• Shim Quantities		+
• Mapping	+	

ARAN™

SUBSYSTEMS

- THEIR UNIQUE **FEATURES**
- HOW THEY **FUNCTION**
- THEIR **BENEFIT** TO YOU THE USER

FEATURE	FUNCTION	BENEFIT
• Axle-mounted time-stable Aerospace piezoresistive accelerometer sensor.	• Measures vertical accelerations of axle representing average roughness of two wheelpaths.	• RMSVA and MAS provided in real time. • Measurements repeatable over long time periods. • Accurate simulation of user roughness perception.
• Body-mounted time-stable aerospace piezoresistive accelerometer sensor.	• Measures vertical body accelerations which are stored in retrievable raw data form.	• Enables post collection calculation of longitudinal profile, Average Rectified Slope, Average Rectified Velocity and International Roughness Index.
• Snap-out accelerometer module.	• Variable orientation of accelerometer provides gravity-based total system calibration in minutes.	• Ensures system is functioning properly without frequent and extended calibration test runs.
• Digital computer with spatial filtering	• Filters out wavelengths of less than 1 foot and greater than 300 feet.	• Facilitates wide speed range of operation with consistent roughness wavelength sensitivity.

FEATURE	FUNCTION	BENEFIT
• Front bumper-mounted ultrasonic bar.	• Up to 13 environmental sensors measure pavement surface profile of 6 to 12 feet lane width including wheel-track ruts.	• Identifies and quantifies pavement surface distortions including ruts. • Provides input for shim quantity calculations for rehabilitation projects.
• Ultrasonic bar fold-up wing extensions.	• Extend main bar by 2 to 6 feet in length.	• Provide flexibility of operation. • Provide easy bar length reduction for safe transit between job sites.
• Ultrasonic bar calibrating sensor.	• Monitors ultrasonic measurement sensitivity to temperature and humidity.	• Provides empirical basis to correct measurements for air density variations continuously and automatically.
• All-weather neoprene snap-on rubber sensor covers.	• Protect sensors from moisture and dust during transit. • Enables quick conversion to operational system status.	• Minimizes maintenance costs due to extended sensor life. • Saves time in preparing system for operation on site.

FEATURE	FUNCTION	BENEFIT
• Pitch and roll gyroscope.	• Measures pavement longitudinal grade and crossfall.	• Provides detailed measured inventory of grade and crossfall parameters. • Provides input along with ultrasonic bar profile data to calculate shim quantities for rehabilitation projects. • Enables longitudinal profile mapping of hills etc. that influence sight distance pavement marking.
• Precision directional gyroscope.	• Measures actual directional heading from 0 to 360° while negotiating roadway curves at traffic speed unaffected by lateral forces.	• Provides input for calculation of curve radii from 50 feet to 6 miles. • Facilitates **in-motion** management of grade and crossfall gyroscope during curve radius measurement (patent pending).

DISTANCE MEASURING SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• Transmission-driven distance measuring instrument.	• Measures average distance travelled by both rear wheels to .001 mile resolution by dividing wheel circumference into 1200 segments.	• Facilitates data referencing on a station-to-station basis for display and analysis.
• High resolution optical shaft encoder.	• Produces a pulsed signal that can be corelated with a known distance.	• Provides convenient and quick calibration for accuracy to compensate for tire wear.
• Custom on-board DMI control software.	• Produces accurate distance measurements in increasing or decreasing direction.	• Enables measurements to be made in opposing lane directions while maintaining common chainage reference for both lanes.
• Custom on-board calibration software.	• Single pass over a measured distance provides exact number of pulses per mile or kilometer.	• Provides simple, quick and accurate calibration check.

FEATURE	FUNCTION	BENEFIT
• Pair of plug-in condition rating keyboards.	• Using special key matrix, surface distress data is entered onto magnetic recording medium while in motion.	• Surface distress data collection is automated and expedited with greatly reduced labour costs. • 100% of network can be surveyed at lower cost than limited sampling programs done manually on foot.
• Special event keys on condition rating keyboards.	• Data relative to landmarks and roadside appurtenances in 8 categories is entered onto magnetic recording medium adjacent to quantitative data.	• Provides precise location of railway crossings, bridges, overpasses, etc. for reference in editing and data analysis.
• Back-lit liquid crystal display on each condition rating keyboard.	• Displays most recent data entered by operator.	• Confirms data is being recorded as entered by operator.

FEATURE	FUNCTION	BENEFIT
• Main control keyboard.	• Permits entry of roadway section header data and controls all subsystems using special keypad and special function control keys.	• Facilitates systems start-up and in-motion control and updating of header data for continuous operation. • Keypad improves utility and durability versus conventional thumbwheel switches and general keyboard design.
• Back-lit liquid crystal display with viewer angle adjustment on main control keyboard.	• Displays header data identifying section being tested as data is being recorded.	• Assures operator that proper header information is used. • Enables operator to update header data for next section for instantaneous entry when entering next roadway section without stopping.
• CRT data display monitor.	• Displays series of operating menus and "prompt" instructions to help operator set up subsystem operation as well as selected diagnostic functions. • Displays data for all systems in operation as it is being collected.	• Simplifies the operating procedures and speeds up preparation for data collection mode. • Enables operator to monitor data continuously to ensure systems continue to function properly at all times.
• Time Drive software on-board.	• Provides simulated DMI output while vehicle is not in motion.	• Enables subsystem diagnostic and calibration procedures in a stationary mode.

FEATURE	FUNCTION	BENEFIT
• On-board data storage	• Enables data to be recorded and stored on machine-readable floppy disks for automated transfer to home base engineering workstation data bank.	• Considerable reduction in manpower required to collect and transfer data. • Expedites availability of displayed data for analysis and post-collection use.
• On-board data verification software.	• Computer checks data files. • Computer checks detail in data files.	• Provides in-field check of data including detail level to confirm it was collected properly.

B-13-20

FEATURE	FUNCTION	BENEFIT
• Ruggedized Industrial IBM PC-AT	• Construction resists vibration, shock and temperature variations experienced in harsh operating environment.	• Minimized maintenance and down-time costs.
• High-speed sensor signal processing.	• Sophisticated digital filtering, data compression and processing are done simultaneously on all subsystems.	• Reduces data collection costs since all subsystems can be operated on a single pass of the ARAN® .
• Large mass storage capacity.	• Large quantities of raw data can be collected utilizing all subsystems simultaneously.	• Provides a comprehensive data base for home base processing using flexible software and upgraded analysis techniques.
• Wide variety of mass storage medium.	• User can specify mass storage medium to accommodate existing home base facilities.	• Reduces cost of integration with existing home base operations.
• Remote microcomputers.	• Selected subsystems have built-in microcomputers for subsystem control and data acquisition.	• Off-loads processing power of main computer freeing capacity for simultaneous operation of all subsystem sensors.

FEATURE	FUNCTION	BENEFIT
• Speed compensating software provided on-board.	• Provides compensation for variations from reference speed during data collection functions.	• Allows driver to float with varying traffic speeds, minimizing need for restarts due to traffic slowdowns and backups.
• Diagnostic software provided on-board for specific subsystems.	• Permits operator to simulate data collection mode to verify that a specific subsystem is functioning properly.	• Speeds up trouble shooting for source of apparent malfunction.
• Calibration software provided on-board for specific subsystems.	• Enables ARAN® major systems checks for operational status.	• Enables operator to do "before" and "after" calibration checks to ensure all data collected is good before leaving jobsite.

FEATURE	FUNCTION	BENEFIT
• Rear van interior working area including spacious desk top area, drawer space, good lighting, airconditioning and swivel chair.	• Operator can perform data checks editing, video verification etc. in comfortable work space.	• Field verification ensures all data is useable before returning to home base. If reruns are necessary they can be done on the same trip, saving costs of returning to field.

FEATURE	FUNCTION	BENEFITS
• High resolution industrial video camera and recorder equipment.	• Produces continuous through-the-windshield industrial quality video recording of the total roadway including roadside appurtenances.	• Enables agency personnel to play back video tapes in home base engineering work station without taking the time to physically drive the roads. • Provides visual documentation of roadway conditions to support rehabilitation budget needs to management for approval. • Provides documented evidence in defence of accident litigation.
• High resolution pavement camera mounted at top rear and aimed at pavement surface.	• Produces sharp, clear continuous view of one full lane width of pavement surface while travelling at highway speeds.	• Enables playback on unit with noise-free search with still capabilities to facilitate detailed study for surface condition rating purposes.
• Machine-readable video tapes.	• Road section header data is cross referenced on audio track of video tape.	• Permits high speed search on playback and enables software synchronizing of video and digital records by location.
• See-through header information superimposed on video frames.	• Header data can be displayed continuously identifying each location by chainage on video record. (Can be de-selected for unobstructed view).	• Identifies each location by road number, direction, chainage etc. for playback location referencing.
• High resolution video monitor on-board.	• Displays video pictures (as recorded) in rear van work area. • Enables remote monitoring of cameras.	• Enables operator to set up cameras and monitor quality of video recording during system operation.
• VTR computer control card	• Automatically starts and stops VTR equipment.	• Reduces routine operating work load of crew.

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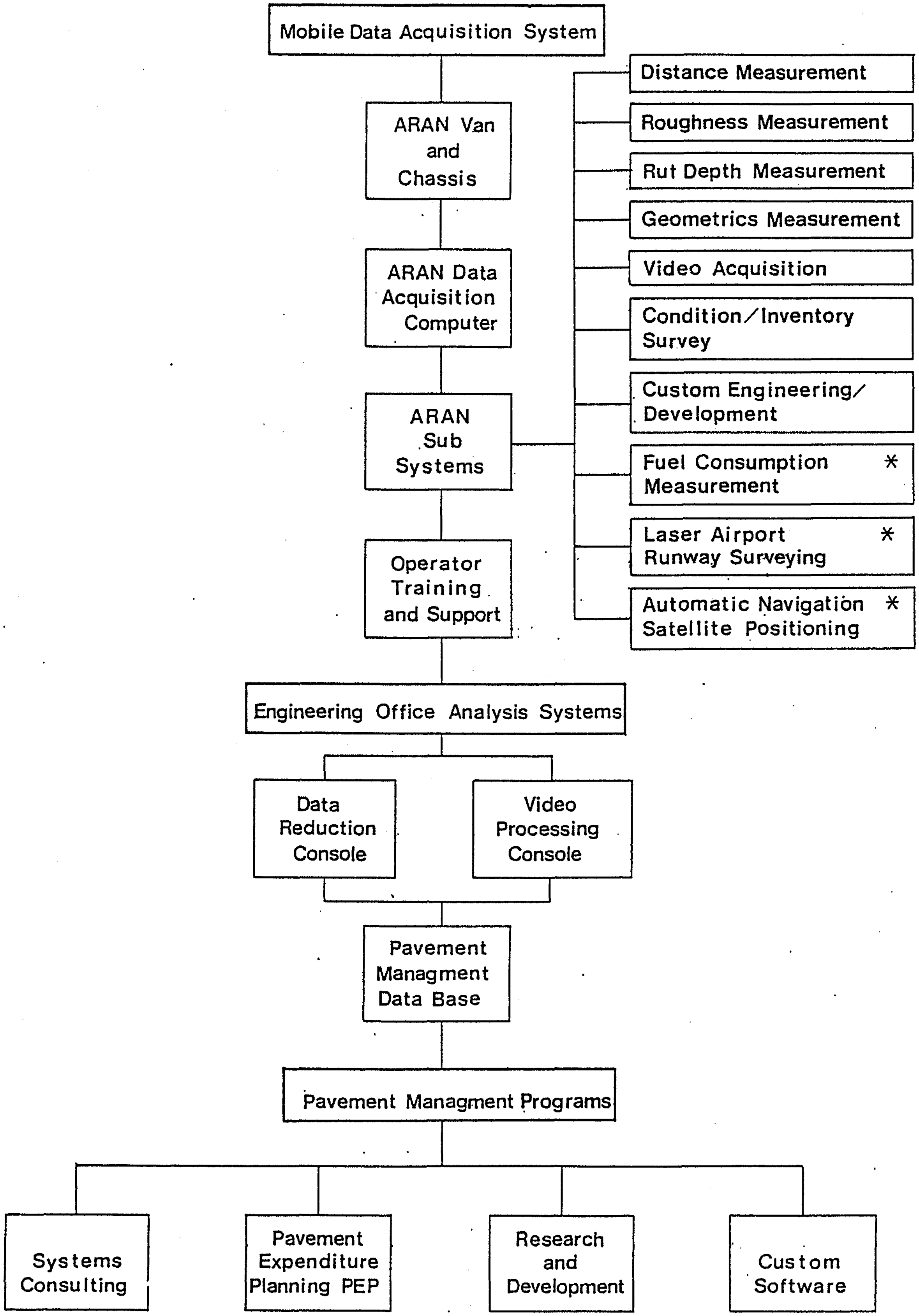
• VTR computer control card.	• Automatically starts and stops VTR equipment.	• Reduces routine operating work load of crew.

FEATURE	FUNCTION	BENEFIT
• Video processing / training centre.	• Facilities monitoring and automated control of video records to enable condition surveys to be conducted using condition rating keyboards. • Facilitates training of personnel to perform surface distress evaluation.	• Condition surveys can be done more leisurely and therefore more thoroughly. • Reduced cost of training versus on-the-road manual surveys. • Provides expansion facilities for automatic digitizing and pattern recognition analysis.
• Data reduction console.	• Facilitates transfer of data from field magnetic medium to fixed disk of PC, editing and displaying data in tabular and colour graphic formats, and producing summary reports.	• Automates data transfer process saving labour and expediting report availability. • Colour graphics reduce analysis time by using colour thresholds to highlight unacceptable pavement conditions for various parameters.

FEATURE	FUNCTION	BENEFIT
• Colour graphic data display software.	• Pavement parameters including Pavement Condition Rating (PCR), Pavement Servicability Index (PSI), ruts, grade, crossfall and curve radius are plotted in a continuous station by station format. Colour thresholds are used to differentiate between levels of acceptability with highly-visible red being unacceptable.	• Saves time in reviewing network status since unacceptable road sections are highlighted quickly as candidates for rehabilitation. Balance of data requires only monitoring in future years for progression toward unacceptable levels.
• Shim Quantity Calculation Software.	• Permits computer calculation of quantity of paving material required to fill ruts, correct other surface distortions and restore design crossfall.	• Permits quick calculation of paving material costs. • Saves high costs of manual pavement surveys. • Enables high-speed highways to be surveyed without traffic interruptions and lane closures.

FEATURE	FUNCTION	BENEFIT
• Complete software package covering all aspects of planning for pavement expenditures including network ranking, performance prediction, prioritization, works programming and budget level prediction.	• Programs are designed to be easily tailored to agency's unique policies, and practices including geo-political budget splits.	• Provides user agency with load-and-go pavement management capability.
	• Colour graphic formats are utilized for data display and analysis as well as reporting functions.	• Provides an integrated system capability from data collection to processing, storage, recall and analysis use for both network and project rehabilitation predesign activities.
		• Provides user with a stand-alone PC-based in-house pavement management decision analysis facility.



* Systems Under Development

HIGHWAY PRODUCTS INTERNATIONAL INC. $ARAN_R$ REFERENCES

Completed $ARAN_R$ Deliveries

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(Mr. Piercarlo Moretti will answer. He speaks English)

Tennessee Department of Transportation
Paul Edens
Assistant Executive Director
Bureau of Planning and Development

Telephone: (615) 741-3339

State of New Hampshire
Public Works & Highways
Concord, New Hampshire
U.S.A.
Attn: Mr. Robert Lyford
Telephone: (603) 271-3344

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Attn: Mr. A. A. Jumikis
Telephone: (609) 292-3560

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Public Transportation
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Austin, Texas 78751

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Mr. Bob Guinn

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Communication
Highway Engineering Division
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M3M 1J8

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Executor Director
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Attn: Mr. Matt Turo

Missouri Highway and Transportation
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Attn: Mr. Mel Sundermeyer
Telephone: (314) 751-4658

ROUGHNESS SURVEYOR , K.J.LAW M8300
NEBRASKA DEPARTMENT OF ROADS

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

PAVEMENT PROFILE MEASUREMENT SEMINAR

EQUIPMENT REPORT - NEBRASKA

Equipment: M 8300 Road Roughness Surveyor

Manufacturer: K. J. Law Co.

Operating Principle: The M 8300 is a non-contact roughness measuring system which uses an ultrasonic probe, an electronic accelerometer, an odometer, and a microprocesser. The microprocesser is preprogammed with a quarter car model to interpret the horizonital and vertical displacement signals, and the vertical accelerations.

The M 8300 measures roughness only. The output can be selected from a menu of options. The most common output is the May's Index in inches/mile and the root mean square acceleration. The output can be printed immediately and/or recorded on cassette tape.

Cost of Operations

The cost of the equipment, not including the vehicle, was about $40,000. An opitional rut depth measuring attachment can also be purchased.
The cost of operation and maintenance is approximately $2.50/mile. The total cost of data collection, analysis, and reporting is approximately $5.00/mile. Productivity varies depending on the intensity of study needed on a given project.

Operating requirements and characteristics

The equipment can be operated by either a one or two person crew. About 15 minutes are needed for setup and system check before operation. The equipment can be operated in traffic at highway speeds so traffic control is not needed. The equipment is vehicle independent but loading must be controlled because probe height is a critical factor.

The equipment measures only surface roughness and is used mainly for pavement condition monitoring at the project level. It is used both before and after construction but is not used for acceptance or quality control.

We have had some difficutly measuring coarse textured surfaces. The equipment was modified by the manufacturer and the problem seems to have been mitigated. We have also had some problems with circuit boards working loose in the microprocessor and with the interface between the tape deck and the processor. The manufacturer is working on these problems. The manufacturer has been quite helpful with troubleshooting and repairs.

Repeatability and reliability of the data is considered adequate. Repeatability of the data is somewhat dependent on the operator since collection must be started at the same point and the vehicle must travel the same path.

ROUGHNESS SURVEYOR , K.J.LAW M8300
COLORADO DEPARTMENT OF HIGHWAYS

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

ATTACHMENT A--EQUIPMENT REPORT GUIDE

MODEL 8300 ROUGHNESS SURVEYOR
MODEL 10100 RUT DEPTH SURVEYOR

A. This is an ultrasonic noncontact system used to measure the displacement between the vehicle frame and the surface being measured. Associated with the ultrasonic probe is a high quality accelerometer, and a digital microprocessor computer system. The probe displacement signal and the acceleration signal are the inputs to the computer program which calculates the roughness index, displays it in digital form, prints it on a printer, and is recorded in a digital cassette recorder to transmit the data directly into a large-scale computer.

A rut depth bar, with five strategically-located, ultrasonic probes, capable of reading rut depth to the hundredth of an inch in each wheel path, is also incorporated in the test vehicle.

The video equipment installed was deemed to be a good idea, since the entire highway system is tested in approximately 15 weeks. Having a current video of all state highways answers many questions not only for our section, but for many other branches in the department.

Software used: PC talk for communications; than dBASE for analysis. Within dBASE, the readings are averaged to one-mile segments and input to the data base.

B. The 8300 Roughness Surveyor is mounted in the rear of the test vehicle and over the left wheel path 12 inches above the pavement. It measures the pavement at 150 pulses per second at speeds to 55 miles per hour (MPH). Our maximum test speed is 45 MPH, so as to give the driver a better opportunity to observe the roadway for the visual distress for cracking and patching between mileposts.

The rut depth bar is mounted in the front of the test vehicle and, when in operation, will span 9'6" wide. Both tests work independently of each other. Therefor, they both have their own keyboard, printer, and cassette recorder.

1. Our 8300 is capable of reading out a Mays roughness index at any interval your program in. However, if nothing is programmed in, it will automatically read out every tenth of a mile, which is the interval we use to test our highway system.

The rut depth is automatically read out, every tenth of a mile, to the hundredth of an inch in each wheel path. Both tests are initiated and terminated by the operator pendent.

2. Output is a hardcopy on board as well as a cassette tape that is then read in the office to a PC.

C. 1. Included in 3.

2. dBASE, PC Talk

3. The 1984 Ford E 250 Van was purchased by K.J. Law Engineers Inc. as directed by the State of Colorado and retrofitted with the M8300 Roughness Surveyor and the 10100 Rut Depth Surveyor. The State of Colorado took delivery of the test vehicle in March of 1985 at a cost of $77,280.00. A breakdown of the cost is listed below:

M 8300 Roughness Surveyor	$39,500.00
10100 Rut Depth Surveyor	22,000.00
1984 E 250 Van	15,780.00
SUBTOTAL	$77,280.00
Option: Video equipment purchased and installed by the State of Colorado (Approximate)	$ 8,000.00
TOTAL	$85,280.00

D. The costs of operation and maintenance have been limited to operator salary and vehicle maintenance. Average runs cost approximately $6 per mile.

E. 1. Checking the accelerometer on the 8300 can be done while zeroing the rut depth probes on the 10100. Otherwise, all the test parameters can be checked and the temperature set while traveling to the starting point for the day.

There is no problem with traffic control as far as speed, because the 8300 maintains accuracy while staying with traffic.

The driver must drive cautiously with the rut depth bar extended.

2. The test vehicle, when fully operational, requires two people. The driver of the test vehicle, while operating the vehicle in a safe manner, must observe the roadway surface to give a percent distress between mileposts for cracking and patching. The driver also

operates the video equipment cameras, recorder, character generator, special effects generator, and checks the TV monitor, to make sure the DMI and everything else is functioning properly. The other person operates the computer terminals for the 8300 and 10100, since both tests work independently of each other. He must monitor the printers, cassette recorders, and key in various events such as bridges, S.H. junctions, county lines, and so on, and be able to put in the percent distress given by the driver of the vehicle, along with the MP number.

3. Testing and videotaping the entire highway system in a 15 week period has provided much information for many agencies, but one that stands out in my mind is a special request by the District 6 landscaping that wanted us to angle our camera to videotape the landscaping through Denver on I-25. By doing this, they could view the monitor in an office rather than risking life and limb going out on I-25 to log the landscaping.

4. The limitations of the test vehicle are that of roughness, rut depth, and video. Some state agencies gather more information on their highways, such as the degree of curves, percent grades, altitude roadway, profile cct. Our test vehicle has been doing an adequate job for us, lately.

   The disadvantages of our test vehicle are that both tests work independently of each other. Therefore, the computer operator must work with two of everything. It would be nice if we had just one terminal and all the data went into one cassette, on one printer, and viewed on the video.

5. The manufacturer, K. J. Law Engineers, Inc., has been very cooperative and helpful in resolving any problems that we have had with the equipment. Since it was one of the first to be fabricated by K. J. Law, it had some problems and many updated features to resolve and incorporate into the system.

6. This being the third year of operation with the test equipment, the 8300 Roughness Surveyor seems to be getting more durable, reliable and repeatable. All the bugs have been worked out and the equipment has been updated with electronics from K. J. Law. This last year has proved to be very successful.

   The 10100 Rut Depth Surveyor has not proved as successful. We are still working with K. J. Law on some of the problems, with high hopes of it being fully operational by the 1988 season.

7. The 8300 Roughness Surveyor has no change in its characteristics on the accuracy of measurements due to various vehicle loadings.

   The 10100 Rut Depth Surveyor, when ready for the day's testing, must find a level pad, and then zero the probs. If there is any significant load change throughout the day, the probes must be rezeroed.

8. Anyone with a valid driver's license and some knowledge of a computer terminal could learn the basic operation of this test equipment with a minimal amount of training. Both tests are menu driven and are almost self explanatory. Once the basic operation is learned, an on the job learning experience exists from day to day as you encounter new problems.

9. With the tax dollar getting tight, the data and videotapes are found to be very useful in making summaries for P.M.S. and presented as a tool in the decision making for the priority of the construction or reconstruction of our highway system.

10. Budget amounts of $70,000 have been used in the last three years.

11. On an average day, the test vehicle will rate approximately 175 miles a day depending on rural or urban highways, that average will fluctuate more for rural and less for urban highways.

12. A-1 Our state highway condition survey is done on the network level in approximately 15 weeks. In that 15-week period, the test vehicle will test our approximately 11,000 miles of state highway,which includes testing any physically divided highways in both directions. To do this in that 15-week period, the test vehicle will travel approximately 22,000 miles.

    A-2 Although we don't do much testing on a project level, any project can be pulled from our network level file because of the tenth-mile readout, and mileposts identified in the "Events" column.

13. The major savings has been in the processing area because of computer processing.

14. For the past three years, there have been many updates and modifications made to the 8300 Roughness Surveyor and a few made to the 10100 Rut Depth Surveyor. Some of the changes to the 8300 were new computer boards capable of changing the format to agree with our CORIS

file for mileage records, and changing the program to a dBASE III form. This eliminates working the test results by hand.

LASER ROAD SURFACE TESTER (LASER RST)
INFRASTRUCTURE MANAGEMENT SERVICES, ILLINOIS

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

ims Infrastructure Management Services

THE

LASER

ROAD SURFACE TESTER

3350 SALT CREEK LANE SUITE 117 ARLINGTON HEIGHTS, ILLINOIS 60005 (312) 506-1500

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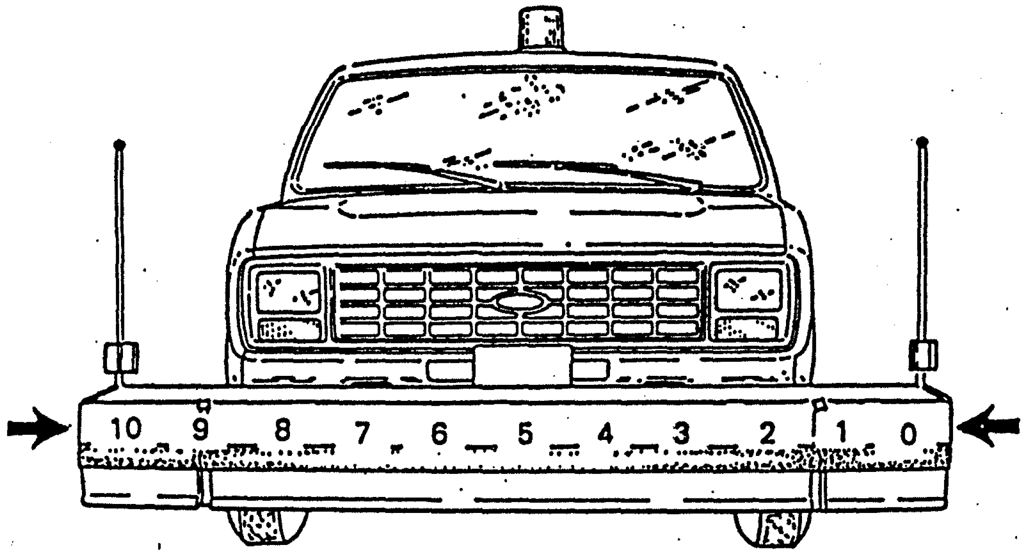
EMPLOYMENT OF LASERS

Eleven lasers are mounted on the front of the van. (see figure 1)



Rut Depth - Utilizes all eleven lasers

Longitudinal Profile - Uses lasers 2 or 8

Macrotexture - Uses lasers 2 and 8

Cracking - Uses lasers 2, 4, 6, and 8

Lasers 1, 3, 5, 7, 9 are "regular" lasers: Regular lasers operate at 16khz and send signals to the rut depth calculation computer only.

Lasers 0, 10 are "angled" lasers: Angled lasers operate at 16khz and are positioned at a 45 degree angle outward, making it possible to measure a width of 3.1 meters with the laser bar only 2.6 meters wide. The angled lasers send signals to the rut depth calculation computer only.

Lasers 2, 4, 6, 8 are "combination" lasers: Combination lasers operate at 32khz and signal to the special rut depth, macrotexture, cracking and profile measuring computers.

MEASUREMENT OF DISTANCE AND VELOCITY

An optical strobe actuated pulse transducer sends 5-volt pulses to a special speed measuring card to determine distance and velocity. The transducer sends 360 5-volt pulses per revolution of the tire. This information is utilized continuously in the crack, macrotexture, rut depth and profile calculations. Calibration of the transducer stores the number of pulses which equal 1 meter. The accuracy of the transducer is reported to be 0.2% over any distance, however, results of our calibration in Austin showed an accuracy of 0.1%.

MEASUREMENT OF RUT DEPTH

All eleven lasers supply signals to a special rut depth measuring card. The rut depth measuring card plots a transverse profile of the pavement and records the deepest rut every 10cm.

At the end of the test section, an average rut depth is reported and a percentage of distance where the rutting was greater than two operator selected limits (normally 1/2" and 1") is reported. The data is reported in real time. Rut depth is measured by the wire method (see figure 2).

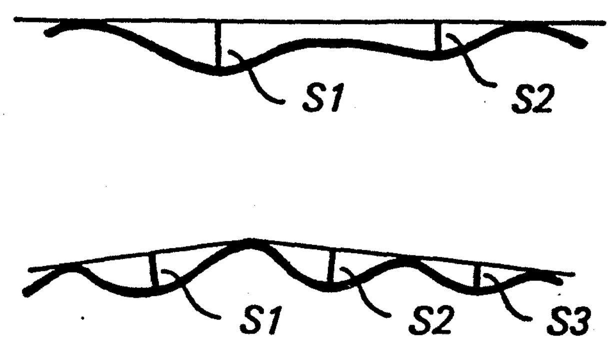


Figure 2

MEASUREMENT OF LONGITUDINAL PROFILE AND DETERMINATION OF ROUGHNESS

To measure longitudinal profile, three measurements are recorded simultaneously at a frequency of 250 hz over the length of the test section.

1. Vertical movement of the laser, measured with the accelerometer

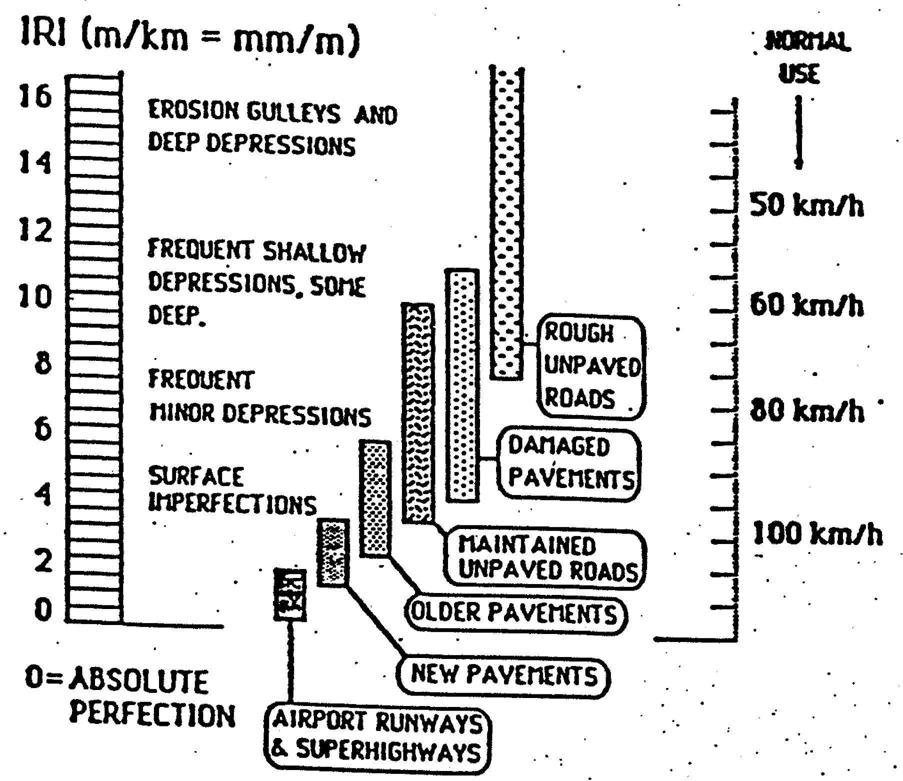
2. Vertical movement of the pavement and laser, recorded with the laser

3. Horizontal velocity of the laser, measured with the pulse transducer (speed measuring device mounted on the right front wheel)

With these measurements, a true profile slope is calculated in the time domain. We sample the pavement at a rate of 250hz.

IRI (Quarter car) and RMSVA (MO) are calculated from the true profile slope for each 20 meter section within the test limits in real time. Approximate limits for various IRI (Quarter car) values are shown on page 5.

IRI ROUGHNESS SCALE



MEASUREMENT OF CRACKING

Lasers 2, 4, 6, 8, (see page 3) supply signals to special crack measuring cards which register cracking and categorize it according to its width and depth. The special cracking measuring cards essentially determine that amplitudes greater than the texture are cracks (see figure 5). Depth and width of cracks are stored in the proper categories in real time (see figure 6).

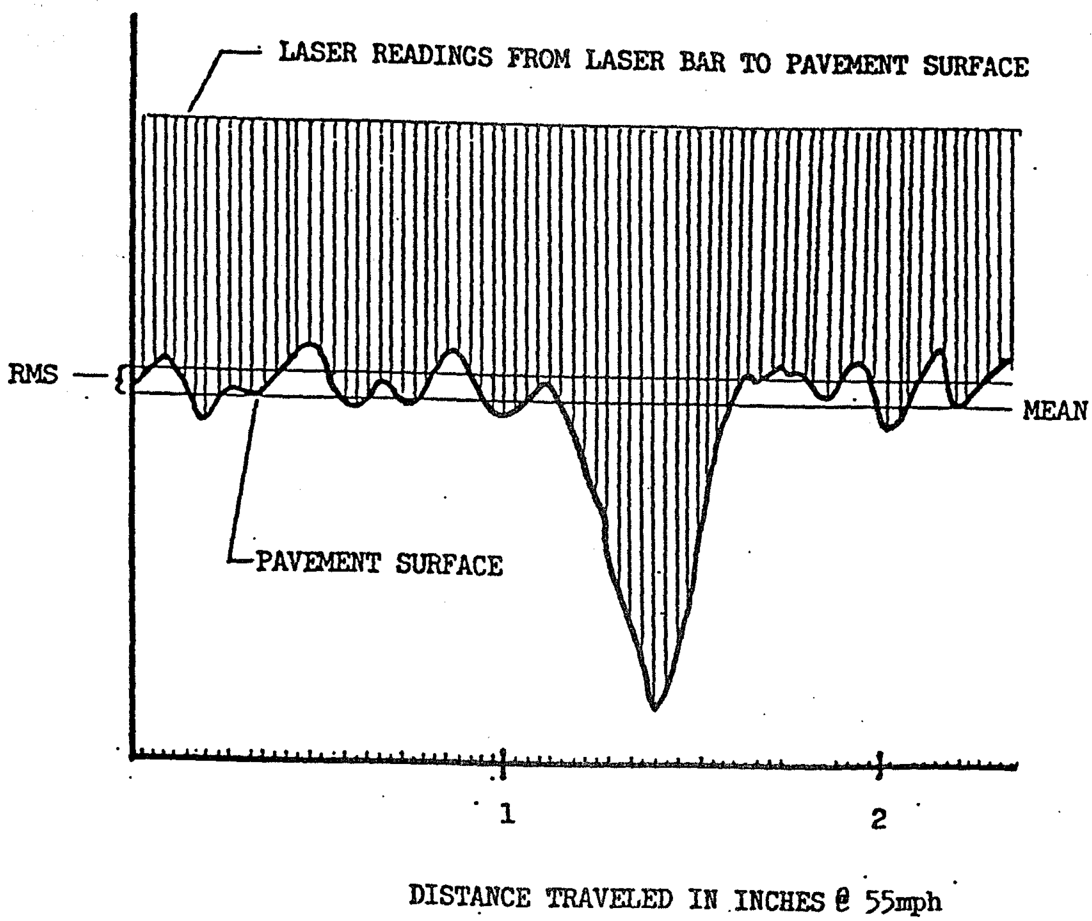


Figure 5

MACROTEXTURE OUTPUT

RMS values meas. in mm	rms		Category limits in mm								
		0.2	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	
			0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
macro 1											
rough	0.83	0	8	28	25	19	7	8	3	0.0	0.0
fine	0.63	0	2	17	43	28	6	1	0	0.0	0.0
macro 4											
rough	0.54	2	48	14	14	10	6	1	0.0	0.0	0.0
fine	0.57	0	6	2	66	21	1	1	0.0	0.0	0.0

Explanation of terms:

RMS: Root Mean Square of the surface texture in mm
macro 1: Texture of left wheel path
4: Texture of right wheel path
rough: Surface texture with wavelength between 10mm and 100mm
fine: Surface texture with wavelength between 2mm and 10mm

PATTERN RECOGNITION

We get an objective density and severity of cracking with lasers 2, 4, 6, 8 (see page 3). Types of cracking are identified by utilizing 8, three position toggle switches (see figure 7). The laser must cross a crack to record it, therefore, longitudinal cracks and edge cracks are rated subjectively with the switches.

TOGGLE SWITCHES

The Laser RST has eight three-position toggle switches available to record additional data. Typical switch designations are shown. The designations can be changed to obtain the desired data.

SWITCH #1	DRAINAGE 1 - Curb and gutter or 5' to 8' ditch with storm sewers. 2 - Greater than 2' ditch. 3 - Less than 2' ditch.
SWITCH #2	SHOULDER TYPE 1 - Curb and gutter or 8' paved. 2 - 8' paved down to 2' paved. 3 - Less than 2' paved.
SWITCH #3	SHOULDER CONDITION 1 - Good 2 - Fair 3 - Poor
SWITCH #4	ALLIGATOR CRACKING 1 - None 2 - Showing small patches of alligator cracking (up to 33%). 3 - More than 33% alligator cracking.
SWITCH #5	EDGE CRACKING 1 - None or a single crack less than 1/4". 2 - Multiple cracking extending 2' from pavement edge but no more than 3'. 3 - Multiple cracking or alligatoring extending 3' or more from pavement edge.
SWITCH #6	LONGITUDINAL CRACKS 1 - None 2 - Less than 1/2" 3 - Greater than 1/2"
SWITCH #7	RANDOM CRACKING 1 - None 2 - Less than 1/2" 3 - Greater than 1/2"
SWITCH #8	EDGE PROFILE 1 - Shoulder even with pavement. 2 - Shoulder lower 1" or more. 3 - Shoulder higher 1" or more.

Figure 7

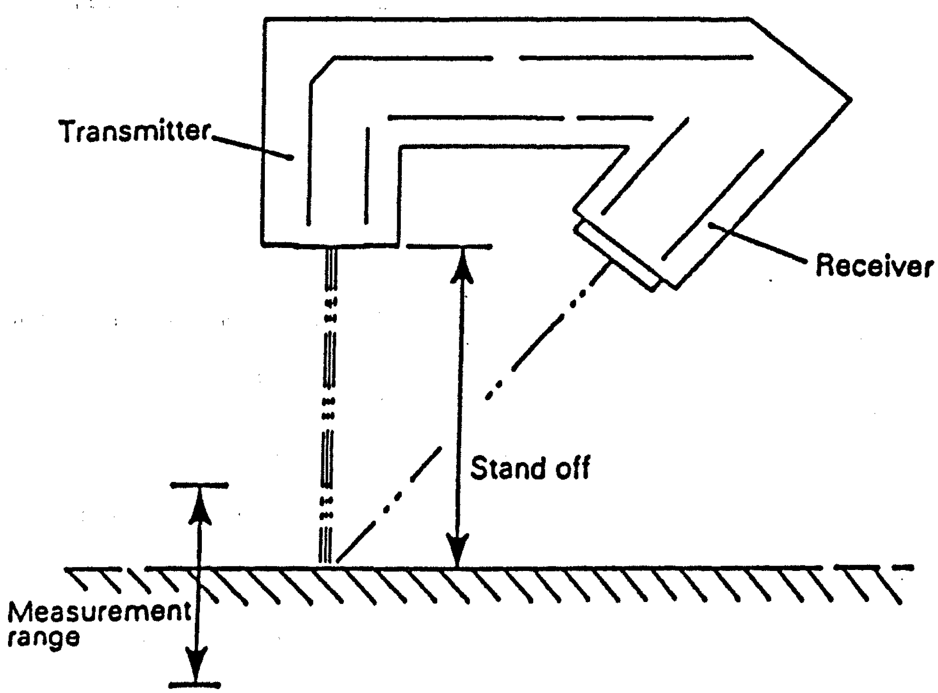
DISTANCE RECORDING BUTTONS

In addition to the eight three-position toggle switches, the Laser RST provides three distance recording buttons. The distance recording buttons are used to collect lengths of distresses, structures, etc., within a test section. When a button is depressed during a test section, the percentage of the total test section length that the button is depressed will be recorded. For example, if a button is depressed at the beginning of a patch and released at the end of the patch, the total length of patching in a test section can be calculated. The button designations are flexible and can be changed to collect desired data.

INTERRUPT BUTTON

The Laser RST is equipped with an interrupt button. The interrupt button is used to cancel out unwanted data (i.e., bridges, railroad tracks, etc.). When the interrupt button is depressed, the measurements of roughness, rut depth, cracking and macrotexture will stop. However, distance will be recorded to allow accurate stationing.

PRINCIPAL OF LASER MEASUREMENT



SELCOM LASER SPECIFICATIONS

	Lasers 1, 3, 5, 9 Regular	Lasers 0, 10 Angled	Lasers 2, 4, 6, 8 Combination
Stand Off Distance	323mm	457mm	323mm
Measuring Range	256mm	362mm	256mm
Laser Foot Print	1mm	1mm	1mm
Frequency	16khz	16khz	32khz

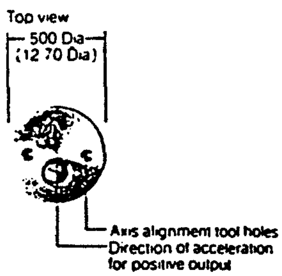
Expected life of the lasers is unknown. However, downtime has been inconsequential because each unit carries 3 spare lasers, one combination, one angled, and one regular.

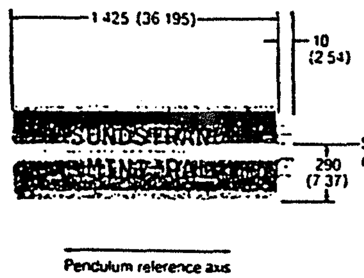
The following specifications apply to all lasers:

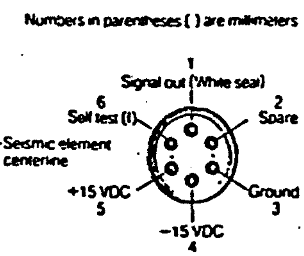
Resolution, Digital	0.025% of measuring range (MR)
Accuracy, at 25 C	± 0.1% of MR
Linearity	± 0.1% of MR
Power Requirements	110/220 VAC, 50/60 Hz
Operating Temperature	0 - 40 C (32 - 104 F)
Storage Temperature	-30 - 70 C (-22 - 158 F)

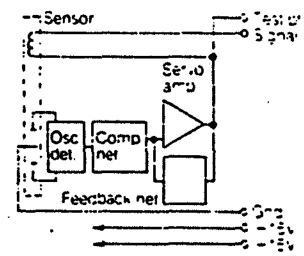
Note: The laser is insensitive to ambient light and surface reflectivity. Surface color, temperature and density are also irrelevant.

ACCELEROMETER SPECIFICATIONS









Range Full Scale	± 1 g to ± 50 g max
Sensitivity, Voltage (Vg)	5 V/g to 0.03 V/g
Output Voltage Linear Range	± 5V max
Sensitivity Current (Ig)	0.3 ± 1% mA/g
Source Impedance	RL = Vg/Ig
Supply Voltage	± 15 VDC, ± 10%, 350 mW max
Natural Frequency	150 Hz, min
Damping	0.3 to 1.0
Linearity	< 0.05% of full range or 0.005 g whichever is greater (BFSL)
Hysteresis & Repeatability	< 0.02% of full range or 0.005 g whichever is greater
Threshold	.005% of full range maximum
Output at Zero g	0 ± 0.010 g maximum
Scale Factor Temperature Coefficient	± 0.02%/°C maximum
Temperature Zero Shift	± 0.00005 g/°C maximum
Axis Alignment Error	0.005 g/g maximum
Case Alignment Error	.75° maximum
Vibration Rectification Coefficient (Sine)	0.00015 g/g^2 20Hz To 100Hz, 0.00010 g/g^2 Above 100Hz
Vibration Limit 20 to 2000 Hz	16 g RMS
Acceleration Limit	250 g
Shock Limit (5 ms pulse)	200 g peak
Temperature, operating	− 55°C to + 71°C
Temperature, storage	− 60°C to + 100°C
Humidity	Sealed Case
Current Self Test (pins 1 and 6)	3.33 ± 0.3 g/mA
Weight	20 grams

COMPUTER SYSTEM

Computer - Primal Data 2000, 6809 chip, an advanced multi-user, multi-tasking 64k.

Storage - Two 8" floppy disks with 1 meg capacity each.

Printer - CITOH

Terminal - ADDS.

Over the past year we have been researching different computers to replace the Primal Data 2000. Through our research we have decided on the Hewlett Packard Integral. During the past eight months the Hewlett Packard has been field tested on the RST in Sweden.

INVENTORY COMPUTER

To organize the raw surface data produced by the Laser RST, an IBM PC is mounted onboard. Inventory data required for test section identification is entered on the IBM PC. The following information is entered:

1. Section number
2. Object number
3. Beginning and ending locations
4. Traffic classification
5. Pavement type
6. Direction of travel
7. Lane tested

The above data is entered in real time and makes organization of the raw surface data quick and easy. The IBM-PC is programmable, so any other test section identification parameters could be included.

CALIBRATION OF EQUIPMENT

CALIBRATION OF LASERS:

A straight edge (calibration bar) is placed under the 11 lasers, then a computer program is used which stores the distance from the 11 lasers to the calibration bar (in units of 1/16mm). This program establishes a straight reference line for rut depth calculations. To test whether or not a laser is working properly, approximately 300 readings to the calibration bar are recorded and the standard deviation is calculated and checked (this is done automatically for each laser). This procedure takes about 10 minutes and is performed daily. If dirt or mud covers the laser while testing, an invalid light will illuminate (one light for each laser). However, in the past three years, this has never occurred.

CALIBRATION OF ACCELEROMETER:

A program is run which prints a reading from the accelerometer in the horizontal position (approximately -1700) then the accelerometer is turned 90 degrees upwards another reading is obtained (approximately -21320). The important thing is that the difference is -19620 (± 50). If the difference is greater than ± 50, a potentiometer must be adjusted. This procedure takes about 15 minutes if adjustment of the potentiometer is required, and about 10 minutes if no adjustment is needed. Calibration of the accelerometer is performed daily.

CALIBRATION OF DMI:

A section of pavement must be measured accurately to 400m or less. A program is run which counts the number of pulses from the transducer as the RST travels the distance. At the end of the section the number of pulses is shown; the distance travelled is input and the computer calculates the number of pulses per meter and stores it. If a 400m or less length is pre-measured, the procedure will take about 10 minutes. This is performed weekly.

PERSONNEL REQUIRED TO OPERATE THE LASER RST

A minimum of three people are required to operate the Laser RST. Their duties involve:

1. Driving
2. Operation of subjective switches
3. Operation of the inventory computer
4. Starting and ending test sections

The driver of the Laser RST has no other duties other than driving. This allows full attention to safe driving.

The operator of the subjective switches also presses the button to start the objective measurements. The Laser RST can be preprogrammed by the operator to end the objective data collection at any desired length. So, full attention to subjectively rated surface distresses is possible.

The operator of the inventory computer enters necessary test section identification information on an onboard IBM PC in real time.

A fourth person is desirable when the project entails large geographic areas such as County or State highway systems. This person should be familiar with the location and designation of the system to be tested.

When testing airfield runways or taxiways, a fourth and fifth person is desirable. These additional people will set temporary flagging to be used as a guide to ensure complete data collection for the entire paved surface.

ADVANTAGES

The advantages of using the Laser RST for a surface condition survey are as follows:

1. Lasers are highly accurate distance measuring devices
2. Lasers take as many as 32,000 readings per second
3. Lasers are insensitive to surface color or reflectivity
4. Lasers can operate in daylight or at night
5. Lasers can operate over a high range of temperatures
6. The Laser RST is used daily in production, therefore, is continually available in the latest "state of the art"
7. The on-board computer is flexible and is operator programmable
8. The on-board computer program is user friendly
9. Date collection is continuous
10. The Laser RST collects data independent of speed
11. Data is collected and reported in real time
12. Data is stored on floppy disk and on hard copy printout in real time
13. The Laser RST data is reported in an easily understandable format
14. Floppy disk allows automated error-free transfer of information to other computers for immediate processing and analysis

TYPICAL COMPUTER PRINTOUT

(LASER ROAD SURFACE TESTER)

Object

Object	6	
Length	187	m
Measured	187	m
Speed	37	km/h
Qcar IRI	4.6	mm/m
MO	3.5	miles/1000
Rut Dpth	13.2	mm
>10.0mm	47	%
>20.0mm	13	%
Button 1	0	%
Button 2	0	%
Button 3	0	%
Switches	2 3 1 3 2 3 1 3	

Mean Prf	0.0	4.5	-1.8	-0.4	0.9	11.0	8.5	8.3	1.8	-3.3	0.0
Dev Prf	0.0	12.3	13.2	10.2	7.1	5.9	6.5	6.3	6.4	7.7	0.0

	3.0				6.0		
	3.0	6.0	12.0	25.0	6.0	12.0	
	6.0	12.0	25.0	50.0	12.0	25.0	100
Crack 1	60	26	14	0	5	4	
2	38	27	9	0	4	5	22
Crack 3	14	9	4	0	0	1	
4	23	15	2	0	4	3	14

			0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0
	RMS	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
Macro 1											
Rough	0.83	0	8	28	25	19	7	8	3	0	0
Fine	0.63	0	2	17	43	28	6	1	0	0	0
Macro 2											
Rough	0.54	2	48	14	14	10	6	1	0	0	0
Fine	0.57	0	6	2	66	21	1	1	0	0	0

EXPLANATION OF TYPICAL COMPUTER PRINTOUT
(LASER ROAD SURFACE TESTER)

(1) Object: IMS Location Number

(2) Length: Actual length of section in meters

(3) Measured: Length of test section sampled, normally (2) & (3) are equal

(4) Speed: Average speed of RST over test section

(5)Quartr car: A ride quality index standard measured in mm per km.

RMSVA (MO): A secondary ride standard of root mean squared vertical acceleration.

(6) Rutdepth: Average rutdepth over the test section of the deepest rut (sampling dist = 10 cm)

> 10 mm: Percentage of the test section with rutdepth greater than 10 mm

> 20 mm: Percentage of the test section with rutdepth greater than 20 mm

(7) Switches: Eight toggle switches for subjective input of environmental and inventory data

(8) No 1: No 2: No 3: Buttons for measuring lengths within a test section -- Value is a percentage of the test section length during which the button was depressed

(9) Cracking:

	Depth #1 (3mm-->6mm)				Depth #2 (6mm +)		MC * 6.0
Laser #	Width #1 3->6 mm	W #2 6->12mm	W #3 12 ->25mm	W #4 25->50 mm	W #2 6->12mm	W #3 12 ->50mm	*Both
crack 1	60	26	14	0	5	4	
2	38	27	9	0	4	5	22
4	14	9	4	0	0	1	
3	23	15	2	0	4	3	14

* Values in the "Both" category indicate numbers of cracks which both laser #1 and #2, or laser #3 and #4 measured at the same time

* MC is Macrotexture Compensation Factor

Note! All values indicate number of cracks per 100 meters

(10) Macrotexture:

RMS values meas. in mm	rms	0.2	0.2 0.3	0.3 0.4	0.4 0.6	0.6 0.9	0.9 1.3	1.3 2.0	2.0 3.0	3.0 5.0	
macro 1											
rough	0.83	0	8	28	25	19	7	8	3	0.0	0.0
fine	0.63	0	2	17	43	28	6	1	0	0.0	0.0
macro 4											
rough	0.54	2	48	14	14	10	6	1	0.0	0.0	0.0
fine	0.57	0	6	2	66	21	1	1	0.0	0.0	0.0

Category limits in mm

Explanation of terms:

RMS: Root Mean Square of the surface texture in mm

macro 1: Texture of left wheel path

4: Texture of right wheel path

rough: Surface texture with wavelength between 10mm and 100mm

fine: Surface texture with wavelength between 2mm and 10mm

(11) Profile: Average transverse profile of lane tested

_ • • • • • • • • • • • _

Mean Profile: Average elevation of each laser above or below the line projected between lasers 1 and 11

Deviation: The standard deviation of each laser within the test section from the mean profile

If we can be of any further assistance

or if you would like

additional information, please contact:

ims Infrastructure Management Services

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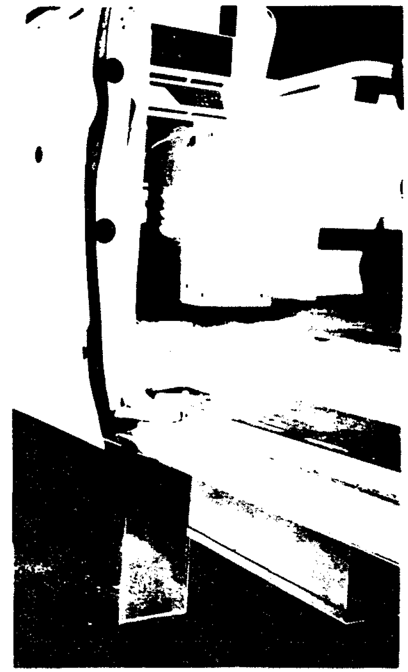
K.J.LAW 690 PROFILOMETER
FHWA,McLean,VA

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

K·J·LAW
ENGINEERS, INC.



MODEL 690 DIGITAL NON-CONTACT SURFACE DYNAMICS PROFILOMETER

- DIGITAL COMPUTER
- NON-CONTACT ELECTRONICS
- ACCELEROMETER ON LIGHT SOURCE BOX

- LIGHT BEAM NON-CONTACT DISPLACEMENT MEASURING SYSTEM

- OPERATOR'S TERMINAL
- CHART RECORDER
- NON-CONTACT SYSTEM SHROUD

MODEL 690DNC ROAD PROFILOMETER WITH PAVEMENT MANAGEMENT PROGRAMS

The non-contact road profilometer measures and records the road surface profiles in each of the vehicles two wheel paths. The profiles are computed by the digital computer housed in the operator's section of the air conditioned measuring vehicle. The profile signals are displayed on the strip chart and recorded on digital magnetic tape for later data processing. Accurate distance pulses serve to clock the profile measurement and computation at speeds from 10 to 55 MPH. Simulator programs compute Root Mean Square Acceleration (RMSA) as an index of road roughness and prints RMSA index along with either May's Meter, PCA Road Meter or BPR Roughometer data from the true profiles obtained. Pavement Management Programs available include: Bituminous Fill, Mill or Grind Level and Smooth, Straight Edge Simulation, May's Meter Calibration. Other PMS programs developed by Surface Dynamics Inc. are available.

K. J. LAW ENGINEERS, INC.
23660 Research Drive
Farmington Hills, MI 48024

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K•J•LAW
ENGINEERS, INC.

SPECIFICATION FOR MODEL 690DNC SURFACE DYNAMICS PROFILOMETER$_{tm}$

The Model 690DNC Surface Dynamics Profilometer$_{tm}$ is an inertial system which measures and records road profile at normal vehicle speeds. The operating principle of the device is similar to the GMR Profilometer described in Highway Research Record Number 121. The Model 690DNC performs all profile computations with a digital computer which provides performance features unavailable in past systems. The system components are:

1.0 Profilometer$_{tm}$ Vehicle
2.0 Non-Contact Pavement Following Sensors
3.0 Accelerometers
4.0 Digital Distance Encoder, Front Wheel
5.0 Profile Computer
6.0 Computer Operating System
7.0 CRT Terminal and Graphics Printer
8.0 Magnetic Tape Recorder
9.0 Roughness Indexes (Optional)
10.0 Profilometer$_{tm}$ Computer Programs
11.0 Optional Computation Programs
12.0 Optional Pavement Profile Data Processing Programs

1.0 Profilometer$_{tm}$ Vehicle

The measuring vehicle shall be a large size van of a design that lends itself to installation of the Profilometer$_{tm}$ equipment with the least amount of modification. The vehicle is to be equipped with both heater and air-conditioning units to provide a uniform temperature and clean atmosphere for the electronic and recording equipment carried in the vehicle. A work console and adjustable seat will be provided for the operator. The digital computer and recording equipment are securely shock mounted, and special soft ride radial tires are used to reduce shock and vibration inputs.

The interior of the vehicle is carpeted to reduce road noise. The vehicle is equipped with a secondary 115 VAC electrical generating system to supply the power required by the Profilometer$_{tm}$ instrumentation, computer, CRT terminal and Graphics Printer. The vehicle is equipped with an automatic speed control device which will allow the driver to select profile measuring speed. A yellow overhead flashing beacon shall be mounted on top of the vehicle.

The profile system contains suitable transducers for measuring road surface profile and for obtaining supporting data such as distance traveled, vehicle speed, and surface identification. The transducers for measuring road surface profile consist of an optical displacement measuring system and a precision accelerometer for each wheel track. The optical system measures the relative displacement of the road with respect to the measuring vehicle body. The accelerometer inertially measures the motion of the measuring vehicle body for the profile computation.

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The vehicle displacement and accelerometer signals are both input to the digital profile computation. Distance and speed information are obtained from the digital distance encoder on the front wheel of the vehicle. Road section identification is obtained with a photocell device whose output is a function of change in road surface reflectivity. This device is capable of detecting identifying marks on the road surface such as reflective tape or white painted lines.

The maximum recommended vehicle speed is 55 MPH. The minimum recommended vehicle speed is 10 MPH. Profile measurements are performed accurately at all speeds between 10 MPH and 55 MPH. Speeds to 70 MPH can be used for runways, test tracks and similar off-road profiling.

2.0 Non-Contact Pavement Following Sensors

The displacement of the road surface shall be measured by a non-contact probe based on the measurement of the angle at which an incandescent spot, projected vertically down from the vehicle on the pavement, is viewed by the system. A change in the vehicle-to-pavement distance causes a change in viewing angle which is related to a change in vehicle vertical displacement, independent of the color or texture of the pavement surface. There shall be a probe for both wheel tracks. The entire assembly shall be protected from the elements and easily cleaned and maintained. The displacement measuring resolution shall be better than 0.010 inches (0.25mm).

3.0 Accelerometers

The acceleration transducer is a force-balance servo-accelerometer with a range of plus/minus 1g. The accelerometer has a low natural frequency and specified damping to minimize the effect of undesireable high frequency accelerations. This high precision device is the inertial reference element of the system.

4.0 Digital Distance Encoder, Front Wheel

The instrumented front wheel has a precision digital distance measuring device which outputs 20 pulses per foot traveled to the profile computer program. This digital distance encoder signal is required for accurate profile computation, accurate distance and the driver´s accurate digital speedometer.

5.0 Profile Computer

The profile signal processing is performed by a digital computer mounted in the vehicle. The profile computations are performed in real time as the vehicle is driven along the road. The digital computer selected has sufficient computation power and speed to perform road profile computations for both wheel paths. Data points are measured and averaged over a running twelve inch interval and then stored as profile points every six inches of travel.

5.1 Wavelength Selection

The operator may select the maximum road wavelength desired. Wavelengths that are longer than the selected wavelength are attenuated in a linear manner. The operator may select any maximum wavelength in feet within the performance capability of the system.

5.2 Long Wavelength Performance Capability

The maximum recommended wavelengths are a function of vehicle speed. The maximum wavelengths are 300 feet at 10 MPH, 1000 feet at 34 MPH (50 feet/sec) and 1600 feet at 55 MPH. The wavelength selection is not a function of vehicle speed and does not change as vehicle speed is changed; however the maximum measureable long wavelength is a function of vehicle speed as stated above. The Profilometer$_{tm}$ must be capable of measuring and reproducing the wavelength content of the road surface profile that is important to vehicle ride. To fulfill this requirement requires wavelengths up to 250 feet with minimal attenuation and minimal phase shift.

6.0 Computer Operating System

The profile computer hardware is supported by a software computer operating system. The computer operating system is the software interface between the system user and the computer programs which compute pavement profile and which process the measured pavement profiles into meaningful system outputs.

7.0 CRT Terminal and Graphics Printer

Communication between the system user and the system itself is through the system CRT Terminal and the Graphics Printer. User commands are effected by an interactive user friendly exchange between messages displayed on the CRT Terminal screen and the user's response through the terminal keyboard. System outputs, including measurement pavement profiles, can be displayed on the CRT screen. System outputs displayed on the CRT screen can also be copied from the screen onto the Graphics Printer on command from the system user. The system Graphics Printer provides hard copy of manually entered data and the selected roughness index. The road profile displayed on the system CRT may also be graphically printed out if a section of unusual interest comes along. During magnetic tape playback the profile may be coupled to the graphics printer and a graphic chart of the entire profile printed out.

8.0 Magnetic Tape Recorder

An industry compatible nine track digital magnetic tape recorder with 1600 BPI phase encoded (PE) recording capability is used to record road profile data. The data is in a file structured format so that each data run is contained in one file. Each data file will contain run documentation data, and the right and left profile data. Right and left profile data is recorded every six inches of road travel with a vertical resolution of 0.010 inches. A single tape recorded at 1600 BPI has capacity for 60 miles of continuous profile measurement. The data can be replayed to the system CRT terminal and graphics printer or can be further processed by a central computing facility.

9.0 Roughness Indexes (Optional)

Vehicle response simulator programs for roughness index calculations are available. The selected roughness index is normalized to read inches/mile and is printed out on the system printer, typically for every tenth mile of vehicle travel. All indexes may be simulated on the computer in the shop, and computed from the recorded profiles.

Roughness indexes offered include RMSA, BPR Roughometer, Mays Meter, PCA Meter, International QI (ARS), etc., and are simulated by the computer system as optional outputs of the digital road Profilometer$_{tm}$ system computed from the recorded profiles.

10.0 Profilometer$_{tm}$ Computer Programs

Computer programs available for the Model 690DNC Surface Dynamics Profilometer$_{tm}$ fall into two categories: 1) Profilometer$_{tm}$ System Programs, and 2) Pavement Profile Data Processing Programs to provide meaningful output for use in the pavement management process. Profilometer$_{tm}$ System Programs include the following:

- 10.1 Profilometer$_{tm}$ System Programs
- 10.2 Road Profile Computation Program
- 10.3 Transducer Calibration Program
- 10.4 Distance Encoder Calibration Program
- 10.5 Magnetic Tape Playback Program
- 10.6 Magnetic Tape Recovery Program

10.1 Profilometer$_{tm}$ System Programs

Profilometer$_{tm}$ system programs are an integral part of the pavement profile measuring system and are included in the base purchase price of the Model 690DNC Surface Dynamics Profilometer$_{tm}$.

10.2 Road Profile Computation Program

Upon initiation of the Road Profile Computation Program, the program interactively leads the user through a friendly sequence of setup question and answer exchanges designed to collect pertinent historical descriptive information on the pavement whose profile is to be measured. The information collected includes: date, time, run number, project number, laboratory number, direction measured, distance measured, operator, driver, beginning mile post, beginning description, ending description, road surface, material condition, weather, temperature, measuring speed, and filter wavelength (in feet). After this information has been entered, the program asks if the information and the subsequent pavement profile measurements are to be recorded on the digital magnetic recorder tape. If the information is to be recorded on tape, the information just collected is read out to tape and stored as a "Tape Header" along with the pavement profile information which will be recorded as the profile measurements are made. After the profile measurements have been made, the user has the ability to again enter comments about the profile measurements just made. Upon the completion of the setup question and answer exchange, the system is ready to measure road profile.

The computation of road profile is initiated automatically by the system upon the completion of the setup operation. The functions performed by the profile computation program are:

Read System Transducer Outputs
Compute Pavement Profiles
Store Pavement Profiles on Magnetic Tape
Output Pavement Profiles to CRT Terminal

The profile computations are performed by a digital mini-computer in the spatial domain, that is as a function of distance traveled. The compute cycle is initiated by a distance pulse from a distance encoder. At the start of the compute cycle the computer reads the outputs of the system transducer and converts them to digital values for use in the profile computation. The distance intervals between distance pulses, and the speed of profile computation are such that a profile computation for each wheel path is performed at least every one inch of distance traveled at all measuring velocities up to 40 miles per hour. Computation of pavement profile in the spatial domain provides a constant wavelength (in feet) filtering action which is independent of profile measuring velocity or changes in measuring velocities. With this feature pavement profiles measured at one velocity will be identical to those made at another velocity with no operator intervention.

Pavement profile measurements to be stored on magnetic tape are computed for both wheel paths at six inch distance intervals and stored in a binary format with a storage resolution of plus/minus 0.001 inch. Using a magnetic tape recording density of 1600 bits per inch (BPI) approximately 60 lane miles of two track pavement profile can be stored on one 7-1/2 inch reel of tape. Events entered by the operator or automatically by the photocell transducer are recorded along with pavement profile measurements at the distance location where the event was entered.

The pavement profile computation program continuously displays the computed profile measurement signals, for both wheel paths, to the CRT display. Measured pavement profiles are displayed as a function of distance. The amplitude scaling of the displayed profiles is selectable during the setup operation prior to the profile measuring run.

10.3 Transducer Calibration Program

The Transducer Calibration Program is designed to assist the user in the calibration of the entire Profilometer$_{tm}$ system. After the calibration program is initiated by the user, the program automatically calibrates the system accelerometers using the accelerometers self calibration feature. The program then leads the user interactively through the remainder of the calibration procedure including the displacement measuring transducer and the final total system calibration which is performed by bouncing the Profilometer$_{tm}$ vehicle up and down while it is stationary over a fixed pavement surface. As the calibration data is being collected, the system calibration program compares the collected calibration data with acceptable values for the data, reporting unacceptable calibration data to the user through the computer terminal.

10.4 Distance Encoder Calibration Program

The Distance Encoder Calibration Program is designed to assist the user in the calibration of the distance measuring system. The number of distance pulses generated by the distance encoder per unit distance traveled is affected by tire size and tire inflation pressure of the wheel on which the distance encoder is mounted. The program computes a distance encoder calibration factor after the Profilometer$_{tm}$ vehicle has been driven over a known measured distance. This calibration factor is then used on subsequent road profile and distance traveled computations.

10.5 Magnetic Tape Playback Program

The Magnetic Tape Playback Program provides the user a means to examine and verify the validity of pavement profile data stored on magnetic tape after a profile measuring run has been made. The program is initiated, through the CRT terminal, by entering the identity of the profile measuring run assigned by the user in the setup program. The program first prints the header information as entered in the setup operation, and then outputs the recorded pavement profiles on the CRT. The user has the ability to select the profile amplitude scaling for each wheel path. Although this program was designed to verify system performance, it can be used at any time to examine the contents of all pavement profile runs stored on magnetic tape. The observed profiles can be copied from the CRT display to the graphics printer.

10.6 Magnetic Tape Recovery Program

The Magnetic Tape Recovery Program is designed to assist the user in recovering recorded pavement profile data from a magnetic tape that has become corrupted as a result of a computer system failure. Although magnetic tape corruption is an infrequent event, the magnetic tape recovery program is an invaluable utility when needed.

11.0 Optional Computation Programs

Several optional extensions are available for the basic pavement profile computation program. These extensions are designed to provide additional pavement management information. The optional extensions include:

- 11.1 Reinitialization
- 11.2 Cross-Slope Computation
- 11.3 Rut Depth Measurement (Requires 11.2)
- 11.4 Grade Computation (Requires 11.2)
- 11.5 Quarter-Car Simulation and Roughness Indexes

11.1 Reinitialization

The Reinitialization option provides the pavement profile computation program the ability to instantly reinitialize the computation of pavement profile removing all past profile history and providing accurate profile measurement from the moment of reinitialization. This option is valuable where long wavelength content from prior pavement profile measurement masks short wavelength content of interest and the prior pavement profile is not required. It also provides a method of rapid recovery from transient response resulting from measuring vehicle acceleration at start up.

11.2 Cross-Slope Computation

In the basic profile computation program the pavement profiles of the two wheel paths are computed independently with no established cross-slope relationship between the two profiles. The cross-slope computation option provides a valid cross-slope relationship between the computed profiles of the two wheel paths. Valid cross-slope information is important in the simulation of paving equipment and the computation of material quantities involved in the pavement resurfacing process.

11.3 Rut Depth Measurement

Rut depth information is also important in the computation of material requirements in the pavement resurfacing process. Minimum rut depth information can be obtained by measuring the relative elevations of the two wheel paths and the quarter-point (half way between wheel paths). To make the rut depth computation it is necessary to measure three pavement profiles and to have their elevation related by cross-slope information. The rut depth measurement option, therefore, requires hardware to measure a third (quarter-point) pavement profile and to make the cross-slope computation. It will also be necessary to store the quarter-point pavement profile on magnetic tape along with the pavement profiles for the two wheel paths. This will reduce the capacity of a 1600 BPI, 7-1/2 inch reel magnetic tape from 60 lane miles to 42 lane miles.

11.4 Grade Computation

The Grade Computation option is designed to independently sense pavement grade information, integrate it into the measured pavement profile to produce a pavement profile which has a complete spatial wavelength content including pavement grade. The resulting pavement profile measurements may be expressed as vertical elevations at six inch intervals along the pavement surface. The grade computation option includes the cross-slope computation option.

11.5 Quarter-Car Simulation and Roughness Indexes

The Quarter-Car Simulation option computes the response of a simulated vehicle to pavement profile as it is being measured. This option can provide the user with the simulated summary output of the BPR Roughometer, Mays, PCA or Cox Ride Meters. One summary ride index (RI) number can be immediately printed on the user's computer terminal. The ride index number is also stored in the magnetic tape header information for the run if the profile measuring run is being recorded. The Quarter-Car Simulation option allows the Surface Dynamics Profilometer$_{tm}$ to be used as a calibration reference or a replacement* for the response type measuring devices if desired.

* (Request M8300 "Roughness Surveyor" information)

12.0 Pavement Profile Data Processing Programs

Pavement Profile Data Processing Programs are optional programs to be user selected that process measured pavement profile stored on magnetic tape to produce meaningful output for the pavement management process. Programs available for this purpose include:

- 12.1 Pavement Data Analysis and Joint Fault Counting
- 12.2 Research Slab Fault Measuring Option
- 12.3 Straight Edge Simulation
- 12.4 BPR Roughometer Simulation
- 12.5 Mays Ride Meter Vehicle Simulation
- 12.6 Mays Ride Meter Trailer Simulation
- 12.7 PCA Ride Meter Simulation
- 12.8 Cox Ride Meter Simulation
- 12.9 Ride Meter Calibration
- 12.10 Root Mean Square Acceleration (RMSA)
- 12.11 Present Servicability Index (PSI)
- 12.12 Ski Control Bituminous Fill
- 12.13 Ski Control Grind/Mill
- 12.14 Combined Grind/Mill and Bituminous Fill
- 12.15 Pavement Management Data Base
- 12.16 International Roughness Index (IRI)

12.1 Pavement Data Analysis and Joint Fault Counting Program

The Pavement Analysis Program provides the user the ability to read measured pavement profile data from magnetic tape and then to perform an array of data manipulation tasks. After the pavement profile data is read from magnetic tape the user may list and edit the profile data points prior to analysis. The user has the ability to process the profile data to obtain power spectral density (PSD) for each of the measured paths and the relationship of the measured paths as given by a coherency function. One feature of the pavement analysis program is its ability to measure joint faulting of 0.1 inch (2.5mm) or larger, and to count faulted joints in a user selected faulted joint incremental height category (e.g., 0.1", 0.2", 0.3", ...).. The output from this program is a faulted joint count per mile. This information is useful input to the codes and other pavement management programs. Other data analysis tools are available within the program with details being available upon request.

12.2 Research Slab Fault Measuring Option

The Research Slab Fault Measuring Option differs from the Pavement Data Analysis and Joint Fault Counting Program (12.1) in its ability to measure slab joint faulting 0.05 inch (1.0mm) and larger. To be able to use this program the profile data points must be stored on magnetic tape with a smaller distance interval than for normal profiling. This option also includes a modification to the Road Profile Computation Program (10.2) to compute and store the profile data points at the required closer distance interval.

12.3 Straight Edge Simulation Program

The Straight Edge Program is designed to automate the straight edge inspection of pavement surfaces. The program provides the user the ability to enter the straight edge deviation in inches. The program then reads the desired pavement profile data from magnetic tape, simulates the movement of the straight edge down the pavement surface and prints out on the user's terminal the straight edge deviations that exceed the allowable maximum for both wheel paths, as a function of distance. In addition the program computes summary statistics that meet the computation requirements of a pending ASTM standard test method for measurement of rolling straight edge response to traveled surface roughness. Output from the program can be either printed output on the user's terminal or output to a strip chart recorder. Program output to the strip chart recorder is straight edge deviations as a function of distance, for the two wheel paths with the amplitude scaling program selectable by the user.

12.4 BPR Roughometer Simulation Program

The Bureau of Public Roads (BPR) Roughometer Simulation Program provides the user BPR Roughometer output for the pavement profile data stored on magnetic tape. The output is the accumulated displacement between the sprung and unsprung BPR Roughometer masses expressed in inches per mile of pavement profile. The output is computed at the BPR Roughometer measuring velocity of 20 MPH regardless of the velocity used to measure the recorded pavement profile. The BPR Roughometer values are printed on the user's terminal at tenth mile intervals normalized for the one mile units. The BPR Roughometer simulation program allows the user to maintain historical BPR Roughometer data and may allow the early retirement of an antiquated and difficult to maintain BPR device.

12.5 Mays Ride Meter Vehicle Simulation Program

The Mays Ride Meter Vehicle Simulation Program is designed to process pavement profile data stored on magnetic tape to produce the output of a simulated vehicle and Mays Ride Meter device. The vehicle simulation model used is based on the "Golden Car" parameters proposed by Tom Gillespie in NCHRP Report 128, "Calibration and Correlation of Response-Type Road Roughness Systems". The program provides the user the ability to input the ride meter vehicle test velocity. The program output is the Mays Ride Meter index for the simulated Mays Ride Meter system in inches per mile at selectable distance intervals for the simulated test velocity. The output of this program was shown in the NCHRP Report 128 to have high correlation with an actual Mays Ride Meter system on the same road test sections. Other vehicle parameters than the medium sized sedan "Golden Car" can be used such as smaller or larger passenger vehicles, MRM trailers, even large trucks. (For the airfield industry Taxi-Code aircraft simulations are available.)

12.6 Mays-Ride Meter Trailer Simulation Program

The Mays Ride Meter Trailer Simulation Program is designed to process pavement profile data stored on magnetic tape to produce the output of a simulated Mays Ride Meter trailer. The trailer simulation model used is based on standard parameters presented in a proposed ASTM Standard "Specifications for Trailers used with Ride Meters". The program provides the user the ability to input the ride meter trailer test velocity. The program output is the Mays Ride Index for the simulated Mays Ride Meter Trailer System in inches per mile at selectable distance intervals for the simulated test velocity.

12.7 PCA Ride Meter Simulation Program

The PCA Ride Meter Simulation Program uses the NCHRP 128 "Golden Car" parameters in the simulation of a vehicle and PCA Ride Meter responding to a measured and recorded pavement profile. The program provides the user the ability to input the Ride Meter vehicle test velocity. The program output can be either the PCA Ride Meter statistic or counts per mile at selectable distance intervals for the simulated test velocity.

12.8 Cox Ride Meter Simulation Program

The Cox Ride Meter Simulation Program also uses the NCHRP 128 "Golden Car" parameters in the simulation of a vehicle and Cox Ride Meter responding to a measured and recorded pavement profile. The program provides the user the ability to input the ride meter vehicle test velocity. The output from the Cox Ride Meter simulation program is Cox Ride Index for the selected distance intervals.

12.9 Ride Meter Calibration Program

The Ride Meter Calibration Program provides the user the ability to compute a calibration factor which can be used to convert Ride Meter Index (RI) values for a particular ride meter into a standard measurement scale. The calibration method used in this program is the method recommended in NCHRP Report 128, "Calibration and Correlation of Response-Type Road Roughness Systems". Inputs to the Ride Meter Calibration Program are pairs of ride index data points obtained from the ride meter being calibrated and from the ride meter simulation program for the type ride meter being calibrated (Mays, PCA, Cox...) for road test sections covering the roughness range of interest. The output of the program is a calibration equation relating the ride meter being calibrated to the standard measuring scale for that type meter.

12.10 Root Mean Square Acceleration (RMSA) Program

The Root Mean Square Acceleration (RMSA) program computes the RMS acceleration of the measured pavement profile recorded on magnetic tape. Input to the program is the simulated vehicle velocity. The RMSA values, expressed in G´s, can be printed on the user´s terminal at user selected distance intervals. RMSA is a valuable tool in evaluating pavement ride quality and correlates highly with subjective ride quality data (PSR). (See 12.11)

12.11 Present Servicability Index (PSI) Program

The Present Servicability Index Program computes PSI from measured pavement profiles previously recorded on the magnetic tape. The computation of PSI is based on a method developed within National Cooperative Highway Research Project (NCHRP) 1-23, in which PSI is computed from the power present (RMSA) in a selected wavelength band of the measured pavement profile. The PSI values computed by this method are independent of pavement type (BC, PCC and Composite) and correlate highly (r = -.94) with subjective ride quality as determined by independent rating panels. The program output is PSI values from 0 to 5 over user selected distance intervals.

12.12 Ski Control Bituminous Fill Program

The Ski Control Bituminous Fill Program simulates the paving process of a bituminous paving machine whose screed is controlled by the movement of the center point of a thirty foot paving ski. The program simulates the paving of up to two layers in one computation. User inputs to the program are: lane width, number of layers (1 or 2), thickness of layers, weight of material in layers and ride quality inspection parameters. Outputs from the program, printed on the user´s terminal, for each layer are: leveling volume, thickness volume, total volume, leveling weight, thickness weight, total weight, and ride quality inspection results. In addition to the printed output the resulting pavement profiles may be output to the graphics printer as a function of distance. Other paver controls such as multi-foot skis, etc., can be simulated.

12.13 Ski Control Grind/Mill Program

The Ski Control Grind/Mill Program simulates the pavement removal process of a pavement grinding or milling machine whose depth-of-cut is controlled by the movement of the center point of a thirty foot ski. The program simulates up to two pavement removal and inspection passes in one computation. User inputs to the program are: lane width, number of passes (1 or 2), depth-of-cut for each pass, and ride quality inspection parameters. Outputs from the program, printed on the user´s terminal, for each removal pass are: volume of material removed and ride quality inspection results. In addition to the printed output the resulting pavement profiles may be output to the graphics printer as a function of distance. Other paver controls such as a multi-foot skis, etc, can be simulated.

12.14 Combined Grind/Mill and Bituminous Fill Program

The Combined Grind/Mill and Bituminous Fill Program simulates a ski controlled pavement removal and/or bituminous paving process. The user can input the ride quality desired after the resurfacing process and the computer program will provide the ski length required to produce the ride quality. The desired ride quality can be input as a ride quality value for any of the conventional pavement inspection devices (Straight Edge, Chloe, BPR Roughometer, Mays Ride Meter, PCA Ride Meter, Cox Ride Meter, or Root Mean Square Acceleration). The computer program simulates the inspection device on the computed pavement surface and adjusts the ski length in the program until the ski length required to produce the desired ride quality has been attained. Another input to the program will be the Bituminous material compaction factor which will enter into the computation of the resulting paved surface profile and the computation of the resulting pavement ride quality after compaction. In another mode the user will be able to input the desired ski length and the ski control resurfacing program will provide the ride quality on the computed pavement profile. In both modes of operation the outputs from the program printed on the user's terminal for each resurfacing pass are: volume of material removed and/or deposited for each pass in the resurfacing process, and the ride quality inspection results. In addition to the printed output the resulting pavement profiles may be output to the graphics printer as a function of distance.

12.15 Pavement Management Data Base Program

The computer equipment employed in the Model 690DNC Surface Dynamics Profilometer$_{tm}$ has the capacity to process and store large amounts of pavement management field data when the system is not being used for measuring profiles. The digital magnetic tape system can store up to 10 million characters on a 7 inch reel of tape. The Pavement Management Data Base Program is designed to provide the user a pavement inventory condition including structural capacity, ride quality, surface condition, skid resistance, etc. The functions performed by this program approach the functions desired for the "Informational Subsystem" on page 15 of NCHRP Report 215 which is reproduced below:

Informational Subsystem

This subsystem involves the collection of more detailed data, appropriate to the size and type of project, so that the project analysis and subsequent implementation may proceed. The types of data and component activities may include the following:

1. Identification of homogeneous subsections within the project or section length (this may in some situations follow filed measurements).

2. Field measurements for or estimates of:

   A. Geometrics (lane widths, layer thicknesses, etc.)
   B. Traffic volumes and loads.
   C. Structural capacity, ride quality, surface condition, ski resistance, etc., for existing pavements.

3. Laboratory measurements to determine material properties.

4. Acquisition of estimates of unit costs of material, construction, etc.

5. Identification of criteria or standards for minimum ride quality, minimum skid resistance, etc.

6. Collection of climatic or environmental data.

7. Collection of available data on construction and maintenance variability.

8. Data processing or input to project analysis subsystem and for transmittal of data file.

12.16 International Roughness Index (IRI)

[The final definition of the International Roughness Index (IRI) has not been finally agreed upon. When the final document is made available the index will be incorporated by appropriate simulation for printout logging and used by international purchasers and other interested owners.] See UMTRI Report 85-14, May 1985.

Designation: E 950 – 83

Standard Test Method for
MEASURING THE LONGITUDINAL PROFILE OF VEHICULAR TRAVELED SURFACE WITH AN INERTIAL PROFILOMETER[1]

This standard is issued under the fixed designation E 950; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement and recording of the profile of vehicular traveled surfaces.

1.2 The test method uses measurement of the distance between an inertial plane of reference and the traveled surface to detect changes in elevation of the surface along the length being traversed by the instrumented vehicle.

1.3 The values measured represent a filtered profile measured from a moving plane of reference using the equipment and procedures stated herein. The profile measurements obtained do not necessarily agree with actual elevation measurements. Selection of proper filtering allows the user to obtain suitable wavelength information for intended data processing.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary information is given in Section 6.

2. Applicable Documents

2.1 *ASTM Standards:*

E 177 Recommended Practice for Use of the Terms Precision and Accuracy as Applied to the Measurement of a Property of a Material[2]

E 178 Practice for Dealing with Outlying Observations[2]

F 457 Method for Speed and Distance Calibration of a Fifth Wheel Equipped with Either Analog or Digital Instrumentation[3]

3. Summary of Method

3.1 The test apparatus consists of a vehicle equipped with necessary transducers and computation and recording equipment to measure and record profile of the traveled surface (**1**).[4]

3.2 The measuring speed, filter wavelength, and sample rate (if variable) are selected. These selections depend on the anticipated roadway conditions and data requirements for the intended data processing.

3.3 The test apparatus is driven at the desired measuring speed over the section of traveled surface to be profiled. Transducers measure vertical acceleration of the vehicle and the displacement between the vehicle and the traveled surface. These transducer signals are combined by the profile computer to produce the displacement between an inertia plane of reference and the traveled surface. The resulting computed profile may be processed on-board or may be recorded for processing at a later time, or both.

4. Significance and Use

4.1 The measurement of vehicular traveled surfaces using an instrumented vehicle with an inertial plane of reference provides an accurate and fast method for acquiring traveled surface profile data (**2–4**).

4.2 The computed profile can be displayed on a strip chart recorder as it is measured for immediate visual evaluations.

4.3 The computed profile can be processed while it is being acquired to produce, by simulation, the outputs of other measuring devices as if these devices had been used to measure the surface (**5, 6**). Devices that can be simulated include the Bureau of Public Roads (BPR) Roughometer, CHLOE Profilometer, Mays Ride Meter, PCA Road Meter and various straightedge devices (**6, 8**).

4.4 The profile data can also be recorded for data processing at a later time to produce the outputs described in 4.3 and for analysis by more complex data processing procedures.

5. Apparatus

5.1 The test apparatus consists of a vehicle equipped with transducers and profile computing and recording equipment. The transducers are used to measure vertical acceleration, displacement, and the distance traveled. The profile computer is used to process the transducer outputs to produce the measured profile of the traveled surface. The test apparatus may have profiling capability for one, two, or more paths. Other supporting apparatus include a driver speed display, a strip chart recorder to display the profile visually, and a mass storage device for long term storage of the measurement.

5.2 *Vehicle Requirements*—The vehicle is the platform for the mounting of the profile-measuring equipment. The vehicle shall be large enough to accommodate all the required equipment without major modification. The engine, steering mechanisms, and suspension components shall be adequate to allow smooth maintenance of measuring speed and direction of travel. The environment of the interior of the vehicle shall be maintained within tolerable limits of the instrumentation and operating personnel.

5.3 *Transducers:*

5.3.1 *Accelerometer*—The accelerometer measures the acceleration used to establish the inertial reference. A high-quality accelerometer shall be used (**2**). The accelerometer shall be mounted on the measuring vehicle with the accelerometer's sensitive axis perpendicular to the traveled surface. The accelerometer range shall be large enough to accommodate the levels of acceleration expected form the bounce motions of the measuring vehicle (typically ±1 g). The accelerometer shall be biased to account for the 1-g acceleration of gravity. The accelerometer shall have a self-calibration external source which, on command, causes the accelerometer output acceleration signal level to change a predetermined value.

5.3.2 *Displacement Measurement*—The displacement transducer measures the relative motion between the accelerometer and the traveled surface. Measuring resolution approaching 0.025 mm (0.001 in.) is required to measure displacement amplitudes that contribute to vehicle ride quality (**6**). However, a minimum resolution of 0.25 mm (0.01 in.) is necessary for useful measurements. The transducer shall be mounted in the vehicle with its measuring axis perpendicular to the traveled surface and in line with the sensitive axis of the accelerometer. The displacement transducer shall measure the vertical distance to the traveled surface continuously, or sample at intervals of not more than 25 mm (1.0 in.). If the displacement transducer physically contacts the traveled surface, such as with a following wheel, it must be of such a design and with sufficient hold-down force to maintain contact with the traveled surface at anticipated measuring speeds.

5.3.3 *Distance Measurement*—The distance transducer produces a series of pulses, the intervals of which represent a fixed distance along the traveled surface. The pulses are used in the processing of profile to convert from a function of time to a function of distance traveled. The pulses may also be used to compute vehicle velocity and distance traveled which are displayed for the vehicle driver. The accuracy of the distance measurement is established by calibration (see 8.2.3).

5.4 *Profile Computer*—The profile computer is used to process acceleration, displacement, and distance transducer outputs to produce measured traveled surface profile. A profile computer terminal shall be provided which will allow the operator to perform system calibration, select system parameters, and monitor system outputs. Filtering shall be provided that permits measuring, without attentuation, road profile wavelengths at least 60 m (200 ft) long at test speeds of 16 to 88 km/h (10 to 55 mph). Computation of surface profile may be analog or digital. The digital computation method used shall ensure

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[1] This test method is under the jurisdiction of ASTM Committee E-17 on Traveled Surface Characteristics and is the direct responsibility of Subcommittee E17.31 on Methods for Measuring Profile and Roughness.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 09.02.

[4] The **boldface** numbers in parentheses refer to the list of references at the end of this standard.

that information on wavelengths as short as 300 mm (12.0 in.) is included. Noise within the profile computer shall be no more than one-quarter intended resolution.

5.5 *Driver Speed Display*:

5.5.1 The vehicle speed shall be displayed conveniently for the vehicle driver to provide an assist to the driver in maintaining the desired measuring speed (see 9.2.3).

5.5.2 The displayed vehicle speed may be computed by the profile computer from the distance pulses. Other means of measuring vehicle speed are acceptable.

5.6 *Strip Chart Recorder*—A strip chart recorder shall be used to monitor visually and to record system outputs. The recorder may have an externally controlled incremental drive which will allow profile amplitudes to be recorded as a function of distance traveled. Amplitude and distance scaling shall be controlled by the operator through the profile computer terminal.

5.7 *Mass Storage Device*—A mass storage device shall be provided for the recording and long term storage of computed profile. The device shall have the ability to play back the recorded profile for display on a strip chart recorder, for additional on-board processing, or for later processing at a data center. Profile data for recording shall be scaled by the profile computer to maintain amplitude resolution of 0.025 mm (0.001 in.) and to accommodate the full range of amplitudes encountered during normal profile measuring operation. The device shall not contribute, to the recorded data, any amplitude larger than 0.025 mm (0.001 in.).

5.8 *Event Marker*—The operator shall be provided the means to event mark location data manually as part of the data records. The system may use a photocell optionally to sense and record automatically reflecting strip location markers that have been placed on the traveled surface.

6. Safety Precautions

6.1 The test vehicle, as well as all attachments to it, shall comply with all applicable state and federal laws. Necessary precautions imposed by laws and regulations shall be taken to ensure safety of operating personnel and other traffic.

7. Digital Profile Recording

7.1 The computed profile must be recorded at adequate intervals (see 5.4) for accurate representation of the traveled surface for the intended use of the data. The interval for data recording shall not be greater than 150 mm (6.0 in.).

7.2 Where two or more paths of traveled surface are measured, the recorded profile data for the paths shall be at the same longitudinal location along the measured profiles.

8. Calibration Procedures

8.1 Due to the high level of performance required of the traveled surface profile measuring apparatus, it is important that the system components and the entire system itself be subject to a periodic calibration procedure. Also, due to the complexity of the calibration procedure, it is recommended that the calibration procedure be automated to reduce or eliminate operator involvement and decision making.

8.2 *Transducers:*

8.2.1 *Acceleration Transducer*—The acceleration transducer shall have a self-calibration feature that provides acceleration transducer calibration on command from an external source. Although the acceleration transducer calibration shall be initiated by the operator, the actual calibration procedure may be performed by the profile computer. A measure of the acceleration-measuring transducer error shall then be displayed for the operator's acceptance. As an alternative, the acceleration transducer may be calibrated, as a stand-alone device, in the laboratory. In either case, an error larger than 0.005 shall not be accepted.

8.2.2 *Displacement Transducer*—The displacement transducer shall be calibrated by introducing an accurately measured step of displacement. The displacement step shall be at least 25 mm (1.0 in.) and accurate within 0.025 mm (0.001 in.). A measure of the displacement transducer error shall be displayed for the operator's acceptance or adjustment. An error greater than 0.125 mm (0.005 in.) shall not be accepted.

8.2.3 *Distance Transducer*—The distance transducer shall be calibrated by measuring a predetermined distance on a straight section of traveled surface in accordance with Method F457. The measured distance shall be long enough to determine any significant difference between the measured distance and the predetermined actual distance. A measure of the distance transducer error shall be displayed for the operator's acceptance or adjustment. An error larger than 0.1 % of the actual distance shall not be accepted. The transducer shall be calibrated at the measuring speed(s) to be used.

9. Procedures

9.1 *General:*

9.1.1 *System Power*—Turn on electronic equipment prior to the beginning of testing to allow electronic components to stabilize (see manufacturer's operating manual).

9.1.2 *System Parameters*—Select, through the profile computer terminal, the system parameters that define the wavelength content of the surface profile to be measured (see manufacturer's operating manual).

9.1.3 *Calibration Checks*—Perform following calibration checks at the beginning of a day of operation and at any other time the operator may suspect a deterioration of system performance.

9.1.3.1 *Profile Computer*—Check the calibration of the profile computer by measuring the response of the profile computer output, as a function of time, to a predetermined step input of displacement and comparing it with the response previously obtained from properly adjusted profile computer. Evalute the following output response parameters: (*1*) time to first zero amplitude crossing, (*2*) maximum amplitude after first zero crossing, and (*3*) closeness of the final amplitude to zero. The outputs will normally be recorded on strip chart, and differences shall be less than the resolution of the recording.

9.1.3.2 *System*—Check the calibration of the major portion of the traveled surface profile measuring system by the simple procedure of bouncing the vehicle as a unit, while it is stationary, on a flat surface. In this mode of operation, the surface profile is unchanging and the system output should be less than 5 % of the vehicle bounce amplitude. A measure of the traveled surface profile measuring system error shall be displayed for the operator's acceptance.

9.2 *Measuring Speed:*

9.2.1 Better quality profile measurements are generally obtained at higher measuring speeds. Higher measuring speeds might, however, be limited by the ability of the apparatus to measure an extremely rough surface at high speed. Measuring speed might have to be reduced to obtain recorded profile measurements at intevals of 150 mm (6.0 in.) or less (see 7.1).

9.2.2 Avoid measuring speeds below 16 km/h (10 mph) since the quality of the long wavelength content of the measured profile might be affected. Measuring speeds as low as 2 m/s (5 mph) may be used where higher speeds are not practical and long wavelength content may not be important; such as, on very rough roads, railroad crossings, or other special conditions.

9.2.3 Maintain constant measuring speed, and avoid sudden speed changes to minimize unwanted input to the acceleration transducer. The use of vehicle cruise control is recommended as an assist in maintaining constant measuring speed.

9.3 *Test Sections*—In preparation for measuring the profile of a traveled surface the operator should become acquainted with the test section to be measured including the beginning, end, and any other features that should be identified within the test section. If identifying features within the test section are to be recorded automatically by use of the photo cell sensing device, the operator shall place reflecting material on the traveled surface at the locations to be identified.

9.4 *Data Acquisition:*

9.4.1 Enter information about the test section and conditions of the test (see Section 11).

9.4.2 Bring the apparatus to desired speed prior to the beginning of the test section.

9.4.3 Prior to reaching the start of the test section, place both the strip chart recorder and mass storage device in record mode.

9.4.4 At the start of the test section, identify the beginning of the test section as part of the recorded data. This can be done automatically with the photo cell sensing device or manually with the event marker.

9.4.5 Measure the surface profile within a traveled lane as close as possible to the path established by normal traffic.

9.4.6 Observe and check the profile data for correctness as it is recorded on the strip chart. In general, the profile traces for the right and left tracks should be very similar.

9.4.7 Identify, as part of the recorded data, other physical features within the test section that will assist in relating the measured profile to actual traveled surface profile.

9.4.8 Identify the end of the test section as part of the recorded data.

9.4.9 Upon completing the measurement, switch the strip chart recorder and the mass storage device from record mode to standby mode.

9.5 *Data Evaluation for Correctness:*

9.5.1 If there is a question about the performance of the test apparatus for the test run, make an immediate check by measuring the test section again. The measured profile for the two runs should be identical except for variations resulting from differences in the paths that were measured (see 12.1.1).

9.5.2 Evaluate the profile data recorded on the mass storage device by playing the recorded data back to the strip chart recorder. The measured profile played back to the strip chart recorder after the test run should be identical to the measured profile recorded on the strip chart recorder as the test section was being measured. Any difference between real time and played-back profiles indicates an equipment problem.

10. Faulty Tests

10.1 Any observable differences between the measured profiles of the left and right wheel tracks (see 9.4.6) that cannot be attributed to actual differences in the roadway mandates a repeat measurement. Any observable differences between the two identical runs, in accordance with Practice E 178, other than differences due to differences in the paths that were measured, indicates an equipment problem and invalidates the tests.

11. Reports

11.1 The field report for each test section shall contain data on the following items:

11.1.1 Date and time of day,

11.1.2 Operator or driver,

11.1.3 Weather conditions; principally temperature, cloud cover, and wind,

11.1.4 Location and description of test section,

11.1.5 Surface description; type of pavement and condition,

11.1.6 Run number,

11.1.7 Measuring speed,

11.1.8 Direction measured,

11.1.9 Lane measured, and

11.1.10 Filter wavelength.

12. Precision and Bias

12.1 *Precision*—Precision (see Practice E 177) in the measurement of traveled surface profile is considered to be the agreement of repeated measurements of the traveled surface profile of a given test section.

12.1.1 Precision is measured in terms of standard deviation from the mean of a number of samples. These may be root mean square values derived from the measured profile for a prescribed test section length, or the power (or amplitude) of selected spectral bands. The length of a test section shall be at least five times (preferably ten times) the longest wavelength to be analyzed.

12.1.1.1 A standard deviation of 2.5 mm (0.1 in.) or better can be expected (7). Standard deviation is expected to be smaller for short spatial wavelength spectral bands. No estimates can be given at this time. Variations in the lateral position of the tester during replicate measurements may contribute to greater standard deviation and should therefore be minimized.

12.2 *Bias*—Bias (see Practice E 177) in the measurement of traveled surface profile is the degree of agreement between the measured surface profile and the true value for the surface profile measured by a method known to be at least as accurate as rod and level measurements taken at intervals corresponding to the shortest wavelength to be analyzed. The difference between the rms values of the measured and true profiles shall not exceed ±2.5 mm (0.1 in.).

12.2.1 Bias of the inertial profilometer, expressed as the average standard deviation between profile measurements made with the inertial profilometer and filtered profile measurements made with rod and level, can be expected to be better than 2.7 mm (0.107 in.) (7).

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PRO RUT
FHWA

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

PRORUT System - for Road Roughness Profiling
and Rut Depth Measurement
Developed by the University of Michigan
for the
Federal Highway Administration,
Office of Research, Development, and Technology

In building PRORUT, we had two objectives, taking a first step toward a fully integrated pavement condition survey system and filling the need for a relatively accurate and inexpensive profiling system. PRORUT meets both these objectives.

Combining profiling and rut depth measurement was relatively easy since the same sensors are used for both. The system is designed to operate with up to five height sensors, arranged transversely beneath the van, but only three are currently installed. This arrangement gives an average rut depth instead of each rut depth separately. The cost breakdown for this minimal system is as follows:

IBM PC with processing boards and software	$6,300
Bubble Memory	1,500
Digital cassette recorder	3,900
Printer	800
Analog signal conditioner	17,500
Total	$30,000

PRORUT is presently configured for three SELCOM laser sensors, which cost about $35,000. Two accelerometers, one over each wheel-track sensor, and a speed or distance transducer, are approximatley $5,000. This makes the cost of the components, without the van about $70,000.

PRORUT was also operated with infrared transducers instead of the SELCOM units. These are estimated to cost about $8,000 each. These infrared transducers and the analog signal conditioner are non-commercial items and thus cannot easily be replaced in case of a breakdown. But PRORUT was built in 1984, and today commercial data acquisition systems and more powerful computers are available. It should, therefore, be possible to build a similar system at reduced cost. The cost could further be reduced significantly by using ultra-sonic height sensors. These, however, are less precise and have proven unreliable on coarse textured pavements.

The onboard computer contols the system operation, including calibration and data processing. Calibration is accomplished by driving the van on 3-inch ramps, hanging the calibration bar in the center position and following the computers instructions. Calibration takes only a few minutes and should be done twice at the start of each test day. During the calibration, the program adjusts the sensor offset and compares the measured and reference values. Errors greater than two percent cause an error message to be printed, but for practical purposes errors of up to 5 percent are acceptable.

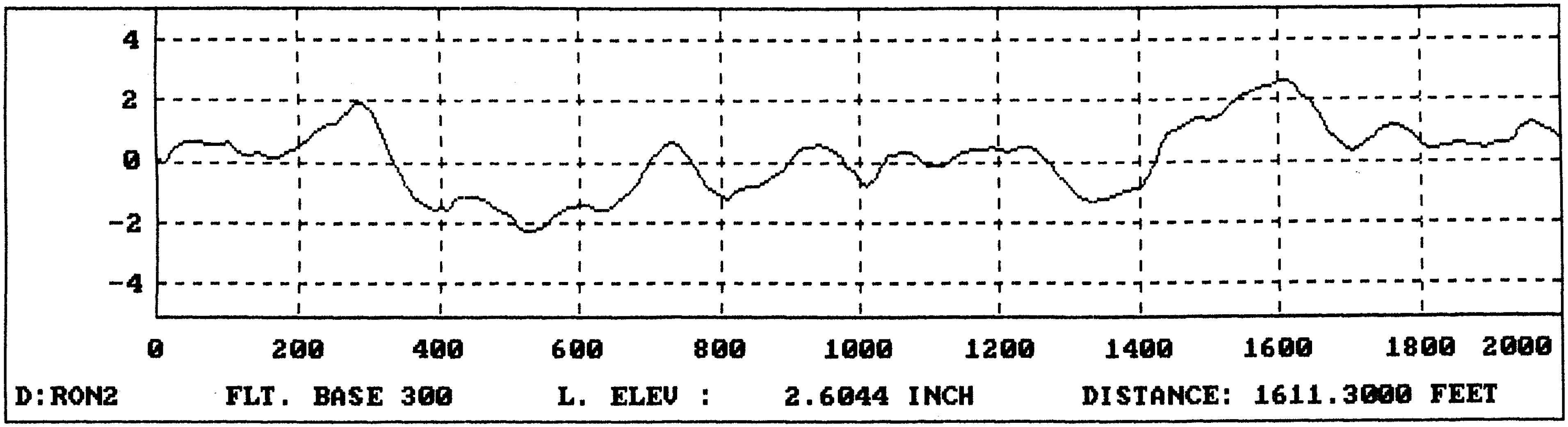
Next the computer leads the operator through a bounce test. The bounce test data are recorded and processed. A successful bounce test will result in an almost straight line record, indicating that the accelerometer signals have cancelled the height sensor signals.

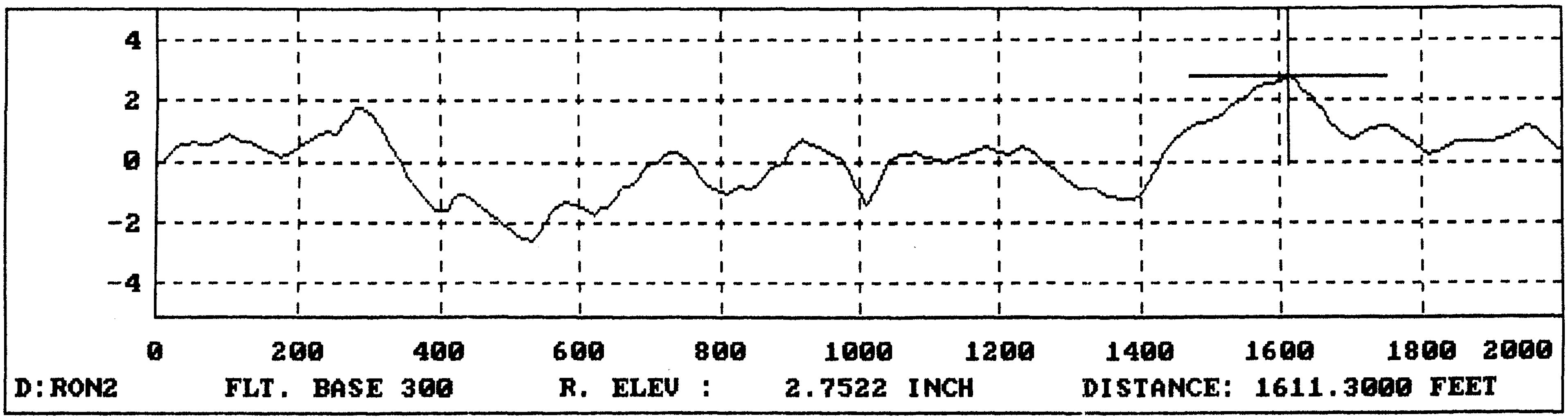
Road tests can be made at any speed between 15 and 60 mph. A sampling rate of between one and six samples per foot may be selected. The filter is automatically set corresponding to the selected test speed. Start of a test is initiated from the keyboard and ended either manually or after a preselected distance.

After completion of a test, the raw data may be checked and plotted, and processed to give the profiles and rut depth. The processed data replace the raw data on the tape. In order to speed up data processing raw data files can be batch processed between test sites. Numerical and graphical outputs can be generated. The averaging distances in the numeric output can be selected. The zoom

feature in the plotting routine allows to plot complete test records, sections of the records, and changing the amplitude scale and plotting base length.

Attached are sample numeric and graphic outputs.


4
2
0
-2
-4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
D:RON2
FLT. BASE 300
L. ELEV :
2.6044 INCH
DISTANCE: 1611.3000 FEET


4
2
0
-2
-4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
D:RON2
FLT. BASE 300
R. ELEV :
2.7522 INCH
DISTANCE: 1611.3000 FEET

DISTANCE - FEET FROM...		TO	L. IRI IN/MI	R. IRI IN/MI	C. RUT INCH
.00	-	50.00	74.82	71.04	-.04
50.00	-	100.00	49.18	57.95	-.04
100.00	-	150.00	84.41	87.32	-.03
150.00	-	200.00	70.21	47.02	-.02
200.00	-	250.00	47.10	62.07	-.01
250.00	-	300.00	99.13	122.80	-.01
300.00	-	350.00	60.27	58.66	-.02
350.00	-	400.00	48.69	47.89	-.02
400.00	-	450.00	81.21	112.96	-.04
450.00	-	500.00	39.34	48.51	-.04
500.00	-	550.00	59.05	63.86	-.04
550.00	-	600.00	69.64	70.90	-.02
600.00	-	650.00	58.83	90.06	-.02
650.00	-	700.00	80.46	140.46	-.02
700.00	-	750.00	64.61	86.48	.02
750.00	-	800.00	50.22	55.43	-.03
800.00	-	850.00	52.52	62.95	-.02
850.00	-	900.00	60.08	66.44	-.03
900.00	-	950.00	48.88	82.46	-.02
950.00	-	1000.00	83.98	68.47	.01
1000.00	-	1050.00	111.50	178.40	.04
1050.00	-	1100.00	77.81	92.96	.03
1100.00	-	1150.00	69.39	88.35	.04
1150.00	-	1200.00	39.24	65.00	.00
1200.00	-	1250.00	45.04	75.02	.00
1250.00	-	1300.00	61.18	73.71	.01
1300.00	-	1350.00	41.11	43.60	.00
350.00	-	1400.00	45.32	42.67	.00
1400.00	-	1450.00	131.50	75.41	.02
1450.00	-	1500.00	94.34	61.19	-.02
1500.00	-	1550.00	58.19	52.30	-.05
1550.00	-	1600.00	62.10	46.03	-.05
1600.00	-	1650.00	48.11	57.35	-.09
1650.00	-	1700.00	52.81	70.54	-.05
1700.00	-	1750.00	48.51	53.42	-.06
1750.00	-	1800.00	49.91	39.01	-.05
1800.00	-	1850.00	62.24	46.78	-.07
1850.00	-	1900.00	32.67	52.00	-.06
1900.00	-	1950.00	56.81	53.25	-.06
1950.00	-	2000.00	66.29	60.73	-.05
2000.00	-	2050.00	46.91	52.50	-.02
2050.00	-	2100.00	86.12	69.21	-.01
2100.00	-	2150.00	73.42	73.86	-.01
2150.00	-	2200.00	51.59	64.14	.02
2200.00	-	2250.00	92.69	57.76	.03
2250.00	-	2300.00	57.97	54.28	.01
2300.00	-	2350.00	51.15	61.63	-.06

The South Dakota Road Profiler

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for
FHWA Demonstration Project 72
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1.0 Introduction

Prior to 1981, the South Dakota Department of Transportation (SDDOT) used a homemade response type meter to evaluate pavement roughness. Like other response devices, the system could detect roughness, but recalibrations for changing vehicle condition were difficult and only partially successful. Long term measurement stability was unattainable.

In 1981 and 1982, SDDOT developed an inertial profile measurement system which measures roadway profile independently of vehicle suspension characteristics. Its cost is low because a noncontact ultrasonic ranging sensor is used to measure the distance from the test vehicle to the pavement surface. The Road Profiler has been used to conduct annual statewide roughness surveys since 1982.

In 1986, additional sensors were installed to allow simultaneous measurement of rut depth and the measurement software was enhanced to allow entry of visual condition ratings. In addition, the ultrasonic ranging sensors' performance on coarse pavement textures was improved.

As the technology has matured, SDDOT has begun to provide technical assistance to other states interested in building similar equipment. Four states have built or are building Road Profilers, and several others are considering building.

Figure 1: The South Dakota Road Profiler

2.0 System Description

The South Dakota Road Profiler was designed to measure roadway profile using relatively inexpensive technology. It consists of a passenger van equipped with electronic instrumentation and data processing equipment suited to real time data collection tasks.

Where possible, standard commercially available components were purchased and integrated into the system. When necessary, mechanical and electronic components were designed and constructed by SDDOT's instrumentation group and machine shop.

2.1 Electronic Instrumentation

The foundation of the Road Profiler's electronic instrumentation is a microcomputer of the Digital Equipment Corporation (DEC) PDP11/73 family. The computer is equipped with a sixteen bit processor, 256 kilobytes of memory, dual eight inch floppy disks, and a twenty megabyte ruggedized fixed disk. A small handheld terminal with membrane keyboard and liquid crystal display is provided for the operator, and an inexpensive dot matrix printer is used to print and plot test results. The computer operates with RT-11, a standard DEC operating system.

The computer is configured to perform the physical measurements necessary to determine roadway profile and rut depth. Two commercially available interfaces--a programmable clock and an analog-to-digital converter--provide timekeeping and voltage measurement capability. In addition, the computer contains three interfaces designed by SDDOT and constructed from breadboard modules compatible with the computer's backplane. The first connects to a transmission pulse sensor and allows the computer to measure the distance traveled by the vehicle. The second operates the three ultrasonic ranging sensors which measure distances between vehicle and pavement. The other provides power and signal conditioning for the accelerometer used to measure vehicle motions.

While the accelerometer and transmission pulse sensor are commercially available items, the ultrasonic ranging sensors are designed and constructed by SDDOT. Like the SDDOT computer interfaces, they are assembled from readily available components using wire wrap techniques on breadboard modules.

2.2 Vehicle Modifications

A few modifications to the standard Ford van are required to support the Road Profiler instrumentation. First, the front bumper is replaced by a 9x4x81" aluminum channel to which the accelerometer and ultrasonic ranging devices are attached. Second, a 500 watt sine wave inverter installed beneath the rear seat supplies high quality 110vac to the computer. Finally, the van is equipped with a high capacity alternator to supply sufficient power to the inverter.

3.0 Principles of Operation

Although the Road Profiler was originally designed to measure only roadway profile, its capabilities have been extended to include rut depth measurement and visual sufficiency rating. Its operation is highly automated, and is designed to interface efficiently with SDDOT's roadway inventory and pavement management systems.

3.1 Profile Measurement

Like several other profile measurement systems, the Road Profiler is an "inertial" device. That is, it measures profile relative to an inertial reference plane inferred from measurements of the vehicle's vertical motion. Specifically, the roadway profile is computed as the difference between the vehicle's position in space and the distance between the vehicle and the pavement surface.

Vertical vehicle motions are sensed by a linear servo accelerometer mounted on the aluminum beam which replaces the vehicle's front bumper. The accelerometer generates an electrical signal proportional to vertical acceleration; this signal is filtered to remove frequencies higher than 25Hz which correspond to extraneous vibrations, then sampled and digitized 125 times per second, and integrated numerically to produce a record of vehicle position as a function of time. The integration algorithm incorporates digital filtering to remove extremely low frequencies (less than 0.01Hz) which contain errors arising from accelerometer tilt and electronic offsets.

The distance between the accelerometer and the pavement surface is measured by an ultrasonic ranging device. A transducer similar to those found on some autofocusing cameras transmits a short burst of 50KHz sound toward the pavement surface. The pavement reflects the sound upward, where it is detected by the same transducer. The distance between the transducer and the pavement surface is computed from the elapsed time between sound generation and echo detection.

Each ranging measurement is subtracted from the current vehicle position to produce the computed roadway profile. The frequency of profile computation is limited by the maximum measurement rate of the ultrasonic transducer, approximately 100Hz. Usually, profiles are measured at one foot intervals at speeds up to sixty miles per hour, but smaller intervals are possible at lower vehicle speeds.

Profiles are measured in the left wheelpath, but right wheelpath operation could be accomplished by repositioning the accelerometer and ultrasonic transducer. Software changes and a second accelerometer would be required to measure both profiles.

Measured profiles are stored on floppy disk for later analysis. Profiles may be plotted, as in Figure 2 which shows the profile measured on Ft. Collins Test Site 8. In addition, the profiles may be used to compute roughness ratings, including the International Roughness Index.

3.2 Rut Depth Measurement

Rut depths are estimated using the profile measurement ultrasonic ranging device located at the left wheelpath and identical sensors mounted colinearly at the center of the vehicle and at the right wheelpath. Rut depth R is computed as

$$R = (h_1 - 2h_2 + h_3)/2$$

where h_1, h_2 and h_3 are the respective distances between the pavement and the left, center, and right sensors. This quantity represents the height of the hump between the wheelpaths, and approximates the average of left and right wheel path rut depths. The three sensor system was chosen because of its simplicity and to avoid problems which result from an overwidth vehicle with sensors mounted outside the wheelpaths. This arrangement demands that the test vehicle maintain an accurate course in the wheelpaths.

Rut depth is measured at every other profile measurement point, so the normal measurement interval is two feet. It is not necessary to record every rut depth measurement, however. If desired, the average of several rut depth measurements may be saved, greatly reducing the amount of storage required. SDDOT normally averages twenty-five measurements to represent the rut depth on fifty foot intervals.

Rut depth measurements are also stored on floppy disk for later analysis such as plotting or summary reports. Figure 3 shows the rut depths measured on Ft. Collins Test Site 8.

3.3 Highway Reference

Profile and rut depth measurements are immediately referenced to the state's highway and reference marker system. The Road Profiler computer contains a Highway/MRM Inventory of all legal highway numbers, the identity of all Mileage Reference Markers (MRMs), and the true mileage of each MRM from the highway origin. As the operator identifies each MRM passed by the test vehicle, the measurement software verifies its identity and flags its location in the profile and rut depth data.

The Road Profiler measures distances between and beyond MRMs by counting pulses generated by the transmission sensor. The measured distance between MRMs is compared to the computer's inventory of true mileage, and significant deviations are flagged on the printed test report. In this manner, mileage errors in the Highway/MRM Inventory can be corrected.

3.4 Sufficiency Ratings

The Road Profiler's measurement software includes the ability to accept the operator's visual ratings of various road conditions. Its computer carries a file which identifies the locations of about two thousand predefined "suffiency sections" on the state's highway system. For each section, seven individual ratings are maintained. As the test vehicle measures profile and rut depth, the computer tracks the its location on the highway, selects the appropriate sufficiency section, prompts the operator to update its ratings, and replaces old ratings with new. At the end of the testing season, the completely updated rating file is used to update SDDOT's pavement management database.

Any items which are observable at normal highway speeds, such as grade elevation, longitudinal drainage, and subgrade stability can be rated in this manner. It is also possible to perform the ratings separately from profile and rut depth measurements. This is particularly useful for urban sections, which are often too short to allow the operator sufficient rating time.

3.5 Calibrations and Tests

The Road Profiler software includes various checks on performance to insure the integrity of measurements. Questionable ultrasonic measurements, identified by unreasonable values or excessive variations, are replaced by interpolation between known valid measurements. The number of replaced values is normally very small, less than one or two per thousand measurements. The accelerometer signal is also monitored to insure proper operation. Profile measurement terminates when an error is detected, and pertinent error messages are displayed.

In addition to these checks, small test programs are provided to individually test the accelerometer and ultrasonic sensors. These tests are performed as a daily check or as needed. Finally, the software allows the operator to change various parameters such as data recording intervals and sensor calibration factors. Calibration of the traveled distance sensor is accomplished by driving the vehicle a known distance.

PRF012: Filtered Profile Plot Program

Demonstration Project 72; Site # 8
Highway: 0000008 From 1.00 + 0.00 to 1.00 + 0.80
Cutoff Wavelength = 300ft

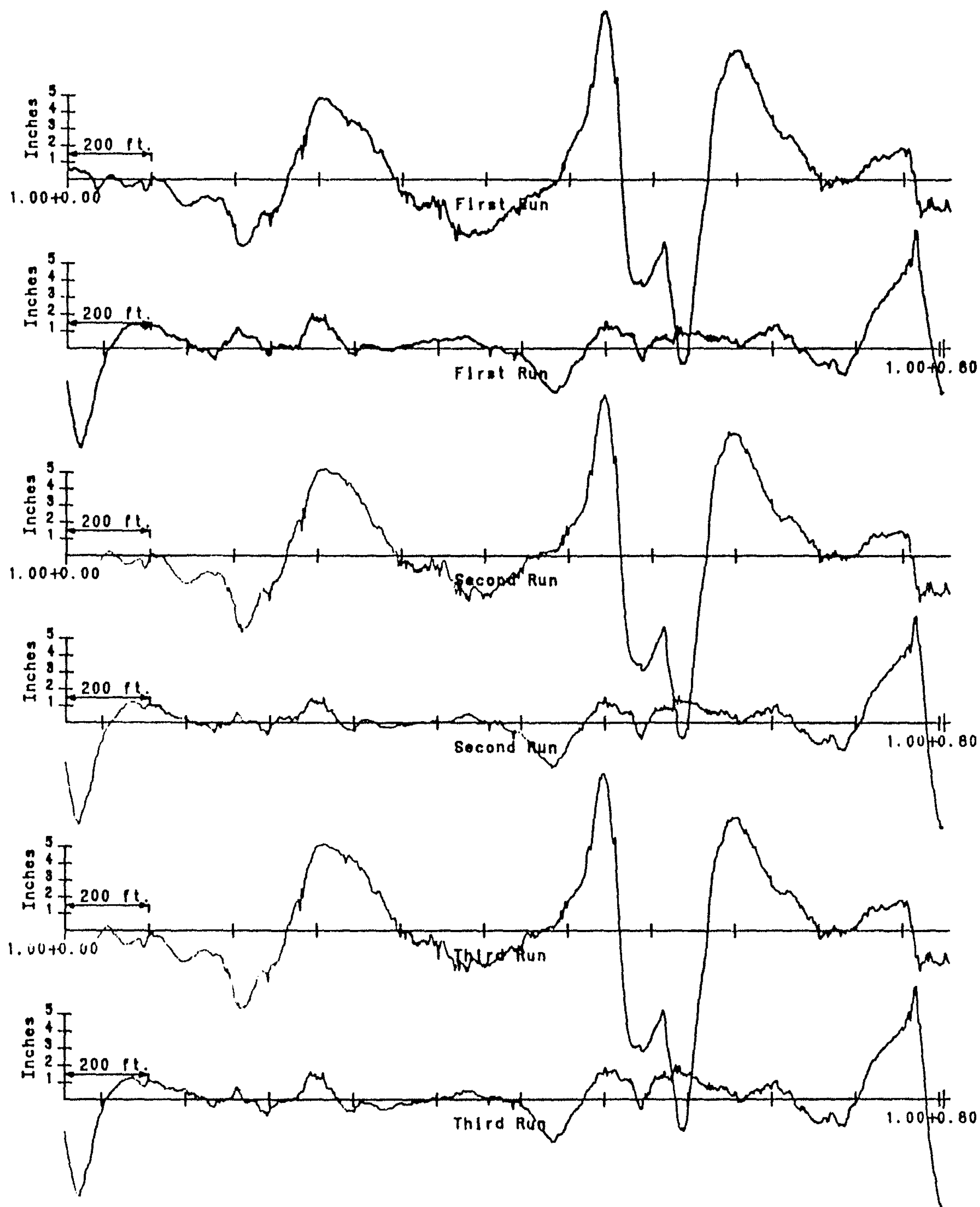


Figure 2: Plotted profiles of Ft. Collins Site 8

RUT012: Rut Depth Plot Program

Demonstration Project 72; Site # 8
Highway: 0000008 From 1.00 + 0.00 to 1.00 + 0.80

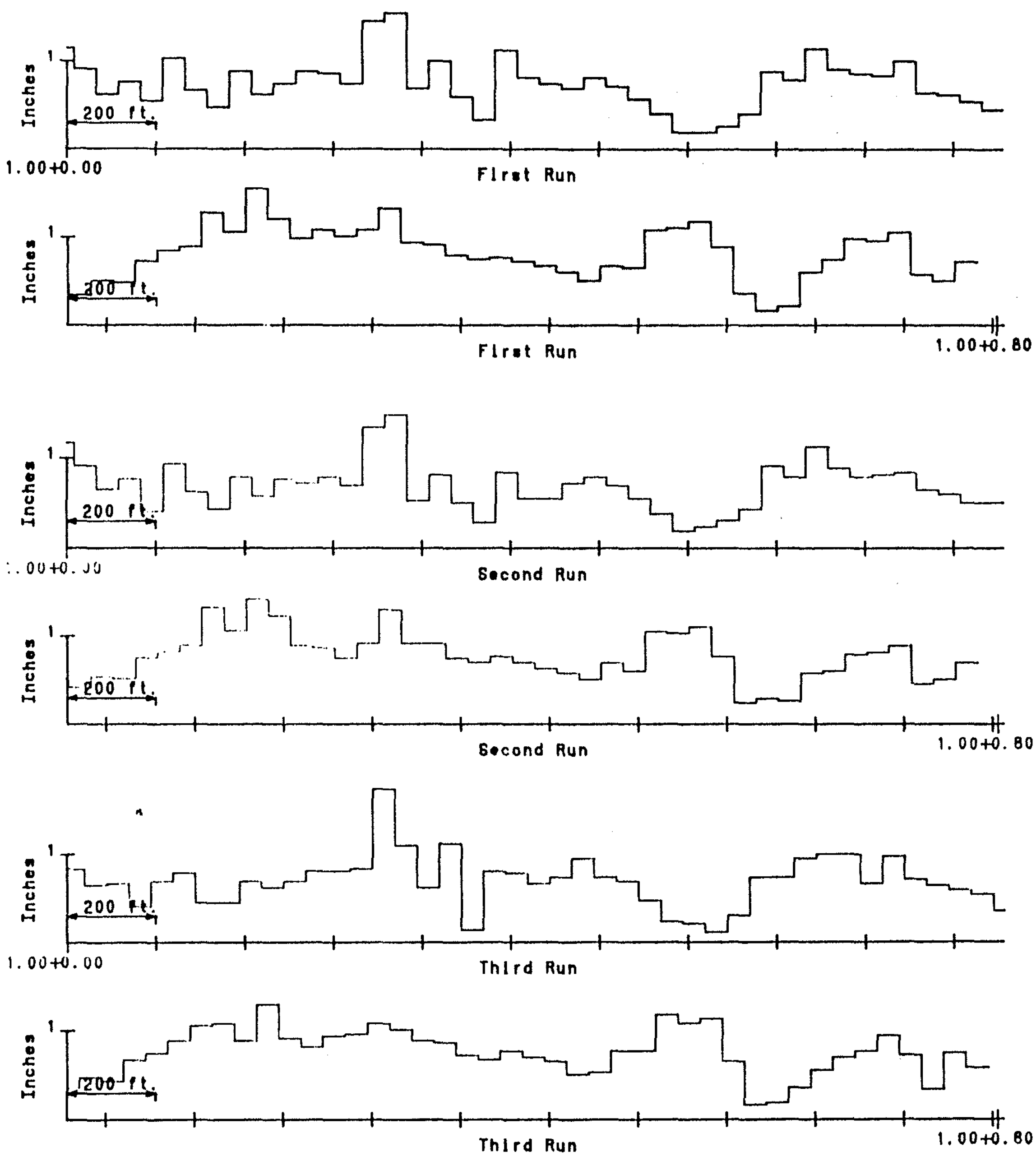


Figure 3: Plotted rut depths of Ft. Collins Site 8

4.0 State's Experience

SDDOT has gained considerable experience using the Road Profiler since 1982. Although it is continously being refined, the Road Profiler is no longer experimental, but has become a dependable "production" tool for conducting pavement condition surveys. Its costs, capabilities and limitations are well established.

4.1 Acquisition Costs

Most of the components used to assemble the South Dakota Road Profiler are commercially available, including the van, inverter, computer, terminal, printer, and accelerometer. It is necessary, however, to construct the ultrasonic ranging devices and the electronic boards which interface the ranging devices, accelerometer and transmission sensor to the computer. In addition, some machining of the aluminum sensor beam and assembly of cables is required. A reasonable estimate of hardware costs is $19,000 plus labor which should not exceed $5000. Software and technical assistance are provided by SDDOT without charge.

Optional equipment can be acquired to make data analysis more convenient. A second computer, costing about $10,000, could analyze data in the office while the test vehicle is in the field and also serve as a spare to the field computer. Another useful option is a pen plotter which allows more versatility and speed in plotting profile and rut depth measurements than does a dot matrix printer. Plotters are available for as little as $2500, depending on the speed and number of pens which are desired. Plotting software is also provided by SDDOT.

Nebraska's experience in replicating the Road Profiler may provide the most realistic estimate of total acquisition cost. During 1987, the Nebraska Department of Roads purchased a van, two computers, instrumentation and spares and assembled their system for just under $50,000.

4.2 Operating Costs

Operating costs of the Road Profiler are quite low. Based upon South Dakota experience, the average cost of statewide surveys is slightly less than $2 per mile, including vehicle expense, salaries, meals and lodging, and supplies. Also included are the costs of transferring roughness ratings, rut depth measurements, and sufficiency ratings to a database resident on a mainframe computer.

These low costs are partially attributable to the experience of SDDOT personnel and the state's predominantly rural highway system, but also result from the fact that measurement and analysis software has been written to match SDDOT's data structures and procedures.

4.3 Traffic Control

Because the Road Profiler is a standard width vehicle and can operate at all normal traffic speeds, no traffic control is required.

4.4 Personnel Needs

The Road Profiler is normally operated by a two man crew. During the summer months when the statewide survey is taken, a college student is hired to drive the test vehicle. Most of the equipment operation is performed by a permanent employee to promote consistency in the visual ratings of pavement condition.

Because the measurement software is written to be very user friendly and to require minimal interaction with the operator, single operator operation is possible. For safety considerations, this is only done for short test runs in areas of light traffic.

4.5 Required Training

Field operation of the Road Profiler is relatively straightforward because the measurement software requires minimal operator intervention. If an operator is familar with the state's highway and reference marker system, about half a day's instruction is sufficient to enable him to perform routine operational checks and conduct profile, rut depth and sufficieny surveys.

Additional training is required to perform the various analyses of profile and rut depth measurements. Although the analysis software is easy to operate, it takes time to develop an understanding of what each analysis means and how to manage the large quantities of information represented by the measurements. Basic competency in using the analysis software might be achieved in a week, but full understanding of all the subtleties involved would take much longer.

4.6 Capabilities and Uses

To date, the primary use of the Road Profiler has been to conduct statewide surveys of pavement roughness and rutting. Each year, SDDOT surveys one lane of its entire state highway system and places summary information into its central highway management database.

Recently, engineering applications have begun to be developed. Measured profiles have beeen used to observe the effects of frost and to estimate quantities of slabjacking required to rehabilitate concrete pavements. Rut depth measurements have been used to estimate the quantities of grinding and/or fill required to eliminate ruts.

The Road Profiler has not been used for construction acceptance. SDDOT uses a profilograph for rigid pavement acceptance because that instrument is used in adjoining states and is familiar to contractors.

4.7 Limitations

As might be expected, the low cost of the Road Profiler contributes to some performance limitations. First, because of inherent limitations in the accuracy of ultrasonic ranging measurements, profile and rut depth accuracy is limited to approximately one sixteenth of an inch (0.005ft). Second, the ultrasonic sensor's maximum measurement rate of one hundred per second restrict the interval at which data may be recorded. At rural highway speeds, the data interval cannot be less than approximately one foot. This limitation results in inadequate sampling of very short wavelengths.

The most significant environmental restriction is that the Road Profiler cannot operate in rain. The ultrasonic ranging sensors, which are open to the air, will electrically short if wetted by rain or road spray.

Early in the Road Profiler's development, measurements were affected by extreme surface textures, particularly chip seals with large aggregates. Improvements made to the ultrasonic ranging devices in 1985 have essentially eliminated the problem, so there is little or no effect from chip seals, open graded asphalts, or concrete tining. One of the test sections in the Ft. Collins demonstration did show significant effect, however. Although the Road Profiler was able to profile the very heavily tined concrete test section, the computed roughness ratings were too high. This result was unexpected because that type of tining had not been encountered before. It is not known whether the tining or a heavy layer of dust on the pavement affected the measurements. Further study will be required.

4.8 Manufacturer Support

"Manufacturer support" is difficult to evaluate because the Road Profiler was constructed in house. In house manufacture can be an advantage or disadvantage, depending upon the capabilities of the operating agency. If the agency possesses sufficient technical expertise, an in house system will usually be well understood and more easily modified and maintained than a purchased system. If such expertise is not available, maintenance becomes difficult or impossible.

SDDOT has provided support to other agencies who have decided to duplicate the Road Profiler by providing equipment specifications, schematic diagrams, technical advise and software. Assistance in final assembly, system initialization and checkout have been provided at SDDOT offices in Pierre, SD. To date, no charges have been made for any of these services.

4.9 Equipment Reliability and Durability

The Road Profiler has proved to be a reliable piece of equipment for high mileage, long duration surveys. The only components which require routine maintenance are the ultrasonic ranging transducers, which must be replaced if they become contaminated by water-borne dirt. On average, each transducer will be replaced once or twice per year, at a cost of less than $20 apiece.

Electronic equipment repair is occasionally required. During the six years in which SDDOT's original computer was used, it required replacement of one floppy disk drive and repair to its power supply. The computer was replaced during the summer of 1987. The sine wave inverter has twice required replacement of a power transistor.

4.10 Effects of Vehicle Loading

Because the Road Profiler measures profile rather than vehicle response to profile, measurements are not influenced by vehicle loading. Tests have also demonstrated that between speeds of fifteen and sixty miles per hour, measurements are essentially unaffected by vehicle speed.

4.11 Productivity

In statewide survey use, the Road Profiler has demonstrated high productivity rates. SDDOT performs its 8500 mile annual survey in approximately eleven weeks of four ten-hour days. On average, approximately three to four hundred miles are driven daily, of which nearly two hundred are tested.

After the field survey is complete, another two or three man-weeks are required to compute roughness ratings and transfer roughness, rut depth and sufficiency information into SDDOT's central database.

5.0 Ride Data

The quarter car roughness ratings (in inches per mile) for the left wheelpath of the Ft. Collins test sections are listed below. Ratings are shown for each tenth mile interval in the section and for the entire section.

Site #	Run #	Speed (mph)	-Interval Roughness Ratings (in/mile)- 1	2	3	4	5	6	7	8	Site Average
1	1	47.7	096	094	076	082	070	078			083
	2	47.7	130	099	070	076	071	078			087
	3	50.1	097	098	075	079	077	084			085
2	1	50.5	125	131	163	143	134	132	166	119	139
	2	50.5	135	144	162	150	146	148	158	112	144
	3	50.5	121	137	157	154	148	156	184	122	147
3	1	49.2	161	190	190	151	155	184	176		172
	2	49.2	159	192	182	179	147	173	167		171
	3	49.6	159	166	188	177	164	167	165		169
4	1	50.2	144	130	136	133	137	153	147	151	141
	2	50.2	140	144	148	141	130	155	152	145	144
	3	49.6	144	138	147	141	142	148	143	144	143
5	1	45.6	235	322	373	392	267	278	312	219	300
	2	45.8	256	321	368	358	248	265	318	223	295
	3	45.9	265	323	345	385	255	278	301	212	296
6	1	48.8	217	207	232	224	194	266	243		226
	2	50.4	228	215	205	238	191	269	246		227
	3	50.1	215	209	209	233	216	276	215		225
7	1	29.7	263	280	281	245	271	329	202		268
	2	24.6	264	281	283	245	271	295	199		263
	3	29.8	266	274	275	240	273	315	200		263
8	1	35.9	258	458	488	359	245	189	300	336	329
	2	32.1	268	483	500	360	225	179	294	327	330
	3	33.2	273	481	486	362	256	183	292	336	334
9	1	50.5	090	081	087	103	134	082	077	089	093
	2	50.3	097	085	088	099	144	088	086	085	096
	3	50.1	094	072	087	105	135	086	084	089	094

6.0 Summary

The South Dakota Road Profiler has become a nearly essential tool in SDDOT's pavement management effort. It provides annual state-wide measurement of profile and rut depth, and records visual condition ratings. Its measurements are finding increasing use in engineering applications such as quantity estimation.

It is the opinion of SDDOT that the Road Profiler provides measurements which are useful for both pavement management and engineering purposes. Furthermore, the costs of equipment acquisition and operation are substantially below other equipment.

SOUTH DAKOTA PROFILOMETER
NEBRASKA

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

(Equipment description is similar to South Dakota's Profilometer as noted in previous section.)

TEXAS SURFACE PROFILOMETER
TEXAS HIGHWAY DEPARTMENT

PAVEMENT PROFILE MEASUREMENT SEMINAR
OCTOBER 5-8, 1987
FT. COLLINS, COLORADO

EQUIPMENT REPORT
TEXAS
SURFACE DYNAMICS PROFILOMETER

A. The Texas Surface Dynamics Profilometer (SDP) measures longitudinal pavement profile in each wheelpath. It does so with a non-contact laser probe and an accelerometer in each wheelpath feeding samples through an analog to digital interface to be filtered, averaged, and stored by a 80286 CPU based computer operating under MS-DOS.

Available software allows the gathering of either ten or twenty samples per foot, either filtered or unfiltered so that the data may later be analyzed using different filters. After filtering, other software is used to average the sample points to obtain the final two points per foot profile. The software most often used for data collection is the ten samples oer foot program. This profile is then analyzed to obtain roughness values.

B. The only pavement parameter measured by the SDP is longitudinal profile. This is stored as two columns of numbers representing thousandths of an inch measurements in each wheelpath. The data is stored on fixed or floppy disk in ASCII format. The data may be output to an oscillograph for graphic representation.

Roughness values are obtained through a software program named VERTAC (VERTacal ACcelleration). VERTAC asks for various instructions, reads the file, plots a graph, and prints a chart of vertical accelerations for each wheelpath as pertains to nine base lengths. Also printed is a simulated Mays Ride

Meter count and a Serviceability Index (SI) on a scale of 0 to 5 (5 = smooth). The program takes about 60 seconds to analyze a 1056 foot (0.2mi.) section.

Below is the opening screen of VERTAC:

```
          VERTAC program (Aug. 86) - Turbo Pascal version


The following information is needed to run the program:

Input file contains profile data at 2 samples/foot.
Numbers for right and left wheels are alternately specified.

Output file refers to the device (printer, terminal, file) to which
the results are copied to.

Pavement type is either rigid or flexible.

(Default (inside parantheses) can be specified by hitting Return).


Data file (VA.DAT): AUS22.20
Output file -- 0 for screen, 1 for printer, or file name (0): 1
Pavement type -- F for flexible or R for rigid (F): F
Skip how many feet before starting the first section (0)? 0
Section length in feet, maximum 1056 (1056): 1056
Display RMS values -- Y or N (Y)? Y
Display new (VERTAC6) PSI -- Y or N (Y)? N
Graph profile data -- Y or N (Y)? Y
```

Below is the output from VERTAC:

****

1056 FT. SECTION BEGINS 0 FT. FROM MARK 0 IN FILE AUS22.20

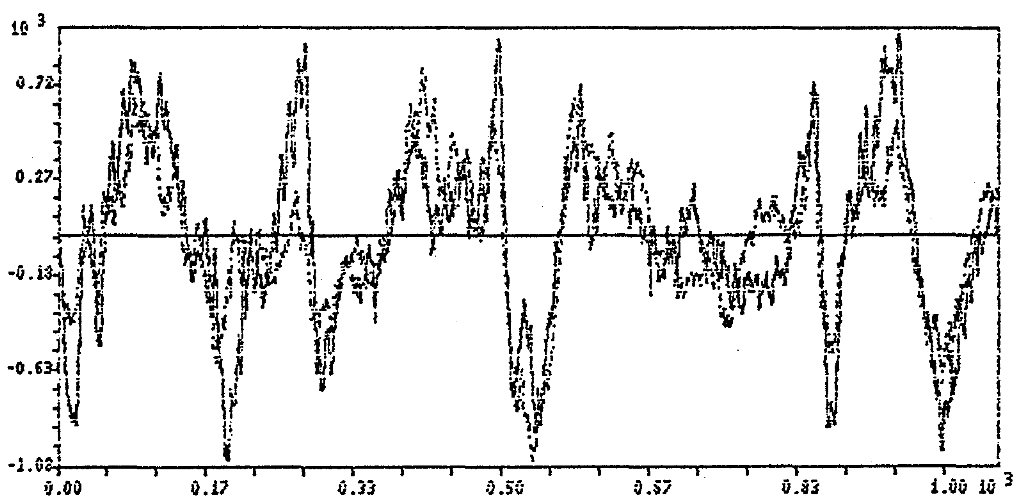
STEP: 0.36 IN. AT 207.0 FT.

BASE LENGTH	RIGHT	LEFT	COMBINED	ESTIMATED SI
0.5	82.62	82.61	82.61	2.70
1.0	36.24	30.47	33.35	2.43
2.0	15.97	10.50	13.23	1.89
4.0	7.07	4.29	5.68	1.60
8.0	2.41	1.72	2.06	1.98
16.0	1.10	0.73	0.92	2.04
32.0	0.39	0.28	0.33	2.51
64.0	0.13	0.10	0.12	2.88
128.0	0.02	0.03	0.03	3.38

MO (MRM SIMSTAT) (COUNTS/.2 MILE): 151.92

FLEXIBLE PAVEMENT SERVICEABILITY: 1.85

****



From: 1.0 To: 1056.5

Commands: (SPACE) Draw profile Print profile Printing...

The vertical scale of the graph is thousandths of an inch times 100, or tenths of an inch. The horizontal scale is feet times 100. This compressed graph is used by the experienced operator to spot abnormalities and judge system performance.

C. Costs of Equipment:

The Texas SDP components cost as follows:

SELCOM Opticator System:

Central Processing Unit	$6000.00
2 Probes @ $15,000	$30,000.00
IR Viewer	$800.00
Accelerometers 2 @ $350	$700.00
Filters 2 @ $200	$400.00
Analog to Digital Interface	$3000.00
Computer	$6000.00
Oscillograph	$6000.00
Printer	$400.00
Truck	$20,000.00
Onan generator	$2500.00
Roof top air cond w/ gas recirc.	$1400.00
TOTAL	$77,200.00

E. 1) Setup of the SDP is done entirely from within the van. Calabration consists of placing a one inch thick block in the path of the laser beam, taking a reading, removing the block, taking a reading and storing the difference in a file on disk. Placing and removing the block calls for getting out of the van.

Currently the SDP gathers data at 20 mph, therefore traffic control is necessary on urban highways. On rural roads and highways and urban streets the truck mounted arrow board and strobes are adequate.

2. Two people are required to operate the SDP: one driver and one operator.

3. The SDP is used as the calabrating insturment for all other roughness devices at the Texas Dep't. of Highways &

Public Transportation.

4. The SDP limited to measurement of longitudinal profile.

5. The SDP is an in-house development.

6. The SDP has proven to be very reliable, and the non-contact probes have eliminated the main source of wear and tear. The SDP repeats better than any other insturment at the Texas DOH.

7. The SDP system is mounted on a Ford E-350 one ton van which seems to have little sensitivity to an extra passenger or two. The vehicle characteristics have never undergone a major change.

8. Very little training is necessary if a person has an understanding of roughness data collection in general, and a working knowledge of MS-DOS.

9. Data collected is used to calabrate other roughness devices, and data correlates very well to the rating panel.

10. The cost of data collection is the sum of wages paid during the time necessary to collect the data plus an additional 90 seconds per 0.2 mile section for analysis and printing, plus depreciation of equipment.

11. The SDP can easily profile 100 miles per day, leaving plenty of time for analysis, printing and file maintenance.

12. The SDP is used for condition survey at both network and project level, and in construction control and acceptance except in instances where the weight of the vehicle makes this impractical. As the calabration norm for other roughness devices it is indirectly involved in most, if not all roughness measurements.

13. A rod and level measurement of a 0.2 mile section by a survey crew recently cost just over $1000.00 and took one day. The SDP can make three runs and analyze and print the data in 15 minutes.

14. Since the installation of the present system there have been no significant modifications.

APPENDIX C

ROUGHNESS EQUIPMENT CORRELATION GUIDELINES FOR OPERATORS

ROUGHNESS EQUIPMENT CORRELATION GUIDELINES

FOR EQUIPMENT OPERATORS

Colorado Department of Highways

Pavement Profile Measurement Seminar

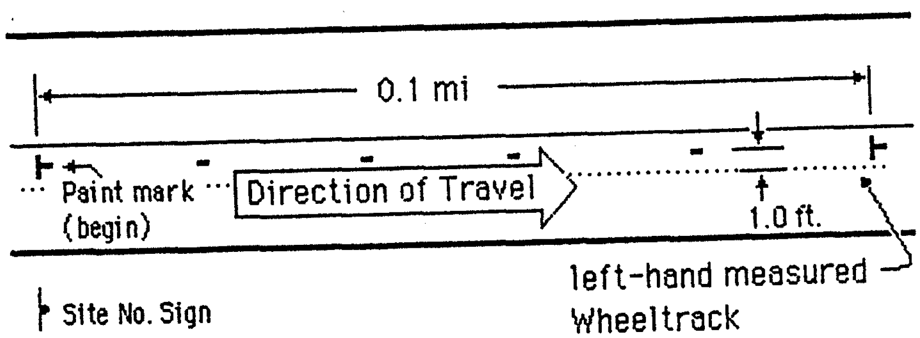
Fort Collins, Colorado

October 5 - 8, 1987

The purpose of this portion of the program was to demonstrate and correlate pavement roughness measuring devices that are currently in use. The sites being tested included flexible as well as rigid pavements with three roughness ranges: smooth, medium, and rough pavements. The sites are located in the Fort Collins area, and are comprised if interstate, arterial, and local streets. Traffic control was provided for low speed test equipment as needed. A map of the test sites is attached to these guidelines for the equipment operators. An orientation session for equipment operators was held on Monday, October 5. The operators were given a tour of the test sites so they could familiarize themselves with the sites location. The south-east corner of the Fort Collins Marriott hotel parking lot had been reserved for equipment parking for the duration of the seminar.

Site Selection: Two test sites for the three roughness categories were selected for flexible pavments, and one site in each category for rigid pavements. These nine sites were typically eight tenths of a mile long with a 1/10 mile approach section.

Site Identification: The test sections had been identified by a roadside sign marking the beginning and end of each test section. In addition, pavement marking of beginning and ending section as well as 1/10 mile subsection were identified within the test sites as shown in the accompanying sketch.



Guidance Striping: To ensure consistency, operators were asked to use this guidance striping, consisting of paint marks at approximately 100 foot intervals, to place their test vehicle in the lane so that the roughness sensors would be measuring wheelpaths.

Operating Speed: Speed during the test runs were held to the posted speed limits with a maximum of 50 miles per hour.

Roughness sensor location: The preferred sensor location for single sensor equipment was in the right wheelpath. However, reference profiles had been established for both wheelpaths, as well as a combination of the two paths using Type I roughness measuring equipment.

Number of Test Runs: A minimum of three, and a maximum of five runs for each test site were required. If the "run average" fell within than 10% of the "site average" as defined below, no further measurements were needed for that site.

$$\text{run average} = \frac{\text{sum of sub-section roughness}}{\text{number of sub-sections}}$$

$$\text{site average} = \frac{\text{sum of run average}}{\text{Number of runs}}$$

Convenient turnarounds were available for most of the test sites for repeat measurements.

Data Recording: Average roadway roughness on all sites were recorded for every subsection (0.8 mile) in one of the following formats by order of preference:

1. Roughness (inches/mile)
2. Other roughness statistics

If a participant's equipment was capable of providing an absolute profile, the data was collected to compare it to the "Dipstick" profile data at a later date.

Data Storage: The preferred storage medium was on 360 KB floppy diskettes in IBM (or compatible) standard ASCII test formats that could easily be transferred to LOTUS 123 spreadsheet programs. The suggested file format was as follows: Date, Time, Run Number, Location (Test Section Number) followed by subsection roughness values. Alternate data storage on hard-copy was also acceptable. Only a few of the participants ware able to use a floppy diskette data storage in general, and none could provide the suggested format. Consequently, all the data had to be transferred from the hard-copies to the LOTUS 123 spread-sheet format.

Analysis: Roughness data from the various participating equipment was compared to each other as an initial attempt. Because of data entry errors, the diversity of the testing equipment as well as test sites, the correlation analysis of overall mean roughness values did not yield a meaningful information about the relationship among the test equipment.

Additional Information: As indicated earlier, all participants in the calibration program were given a tour of the test sites prior to the testing. Once the operators were familiar with the test sites they could perform the testing at their pace, so as not to interfere with other operators. Calibration took place on Monday, October 5, and additional equipment demonstration on four of the test sites was scheduled for Wednesday, October 7. During the Wednesday demonstration runs seminar participants were able to ride in the test vehicles to familiarize themselves with most of the devices.

<u>Reports:</u> Since there is great interest in the various types of roughness measuring device, all test equipment operators were asked to provide written information for their devices. These reports can be found in Appendix B.

<u>Equipment Operation Schedule:</u>

Monday October 5, 1987

8:00 AM	Operator's orientation meeting
9:00 AM	Tour of test sites
10:00 AM - 5:00 PM	Run correlation tests

Tuesday

4:30 - 6:00 PM	Open House - Equipment display in south-east area of hotel parking lot

Wednesday

10:30 AM - 5:00 PM	Equipment demonstration
5:00 PM - 6:00 PM	Open House

CORRELATION SITE DESCRIPTION

Site No.	Description and location	Pavement type	Roughnes
1*	S.H. 68 WB from Timberline Rd to LeMay Ave	flexible	smooth
2	S.H. 68 EB from Timberline Rd to County Rd 9	flexible	medium
3*	I-25 NB from MP 268 to MP 269	rigid	smooth
4	I-25 SB from MP 271 to MP 270	rigid	medium
5	Vine Drive from Lindemeir St to County Rd 9	flexible	medium
6*	Vine Drive from County Rd 9 to Lindemeir St	flexible	rough
7*	LaPorte Ave from College Ave to Shields Ave	rigid	rough
8	Shields Ave from Vine Ave to Wilcox Ave	flexible	rough
9	S.H.1 north of LaPorte Ave	flexible	smooth

(Sites with asterisks also serve as demonstration sites)

APPENDIX D

EQUIPMENT REPORT GUIDE QUESTIONNAIRE

EQUIPMENT REPORT GUIDE

The agencies providing equipment shall include an analysis of the following items in their evaluation of each selected piece of equipment and document its findings in a report.

A. Describe and document the principles of operation of the various categories of equipment and peripherals evaluated. Discuss software availavle and its application.

B. Describe the pavement condition parameters measured by the device. (i.e., roughness, rutting, distress, cross slope, cracking etc.)

   1. Describe output and format of output.
   2. Processing required to get output.

C. Acquisition costs of equipment (from manufacturer)

   1. Hardware
   2. Software
   3. Standard equipment and options available

D. Average costs to operate and maintain equipment.

E. Describe and document your experiences with the equipment as it relates to the following

   1. Operating requirements such as setup and traffic control.
   2. Personnel needs for operation of the equipment.
   3. Capabilities and uses that could be made of the equipment by the Cooperating Agency.
   4. Limitations or disadvantages associated with the equipment.
   5. Manufacturer's support in resolving problems.
   6. Equipment durability, reliability and repeatability.
   7. Effects of various vehicle loadings or changes in vehicle characteristics on the accuracy or repeatability of measurements.
   8. Training necessary for use of the equipment.
   9. Usefulness and reasonableness of collected data.
   10. Average costs of data collection, analysis, and reporting.
   11. Equipment productivity Rates (i.e., miles/day).
   12. Document use of the equipment for the following:

       a. Inventory monitoring/condition survey

(1) Network level
(2) Project level

b. Construction control and acceptance

(1) New construction
(2) Rehabilitation
(3) Reconstruction
(4) Maintenance

13. Cost savings which you have realized by using the equipment.

14. Detail any modifications made to the equipment.

15. The final report shall be prepared by the Cooperating Agency and submitted to CDOH for incorporation in the conference proceedings

Supply ride data in appropriate format for correlation and analysis.