DEMONSTRATION PROJECT NO. 72
AUTOMATED PAVEMENT DATA COLLECTION EQUIPMENT
Roughness and Profile Measurement

Iowa DOT Evaluation of the
PASCO Road Survey System

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16. Abstract
The report compares and contrasts the automated PASCO method of pavement evaluation to the manual procedures used by the Iowa Department of Transportation (DOT) to evaluate pavement condition. Iowa DOT's use of IJK and BPR roadmeters and manual crack and patch surveys are compared to PASCO's use of 35-mm photography, artificial lighting and hairline projection, tracking wheels and lasers to measure ride, cracking and patching, rut depths, and roughness. The Iowa DOT method provides a Present Serviceability Index (PSI) value and PASCO provides a Maintenance Control Index (MCI).

Seven sections of Interstate Highway, county roads and city streets, and one shoulder section were tested with different speeds of data collection, surface types and textures, and stop and start conditions. High correlation of results between the two methods in the measurement of roughness (0.93 for the tracking wheel and 0.84 for the laser method) were recorded. Rut depth correlations of 0.61 and cracking of 0.32 are attributed to PASCO's more comprehensive measurement techniques.

A cost analysis of the data provided by both systems indicates that PASCO is capable of providing a comparable result with improved accuracy at a cost of $125-$150 or less per two-lane mile depending on survey mileage. Improved data collection speed, accuracy, and reliability, and a visible record of pavement condition for comparable costs are available.

The PASCO system's ability to provide the data required in the Highway Pavement Distress Identification Manual, the Pavement Condition Rating Guide, and the Strategic Highway Research Program Long Term Pavement Performance (LTPP) Studies, is also outlined in the report.

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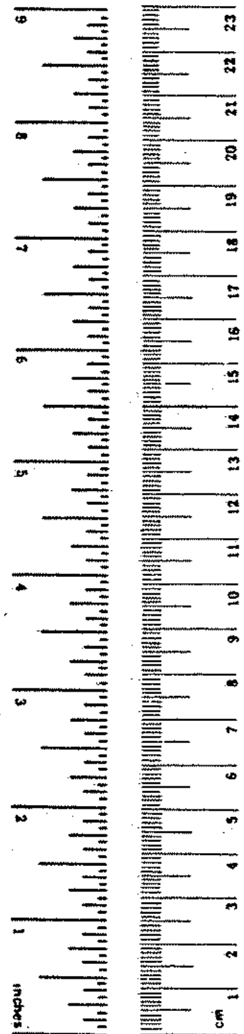
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

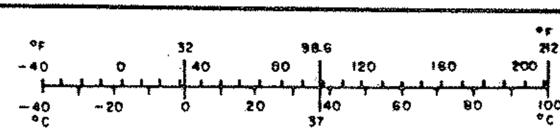
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

Current Practices

In times of limited resources and aging pavement coupled with increasing traffic volumes and truck weights, evaluation of pavement conditions becomes critical in making proper rehabilitation decisions. All available information must be gathered about the surface of the road and the structural strength of the material used in the pavement and roadbed construction so that a proper maintenance and rehabilitation schedule can be developed. In the past, most such information was gathered manually at the Iowa Department of Transportation (DOT). With the advent of computers and high technology, these procedures can now be automated.

PASCO USA, Inc., has developed a fully automated system to give surface condition information. The surface condition is evaluated in terms of roughness, cracking, patching, and rut depth. This matches the information gathered currently by the Iowa DOT by both mechanical and manual means.

In the Iowa method, cracking, patching, and rut depth are physically measured by field crews in accordance with procedures developed at the AASHO Road Test in Illinois in the 1950s. Roughness is obtained with a BPR or IJK roadmeter-type profilometer that is calibrated against the CHLOE profilometer standard. From this the Iowa DOT obtains a Present Serviceability Index (PSI) value that lies between zero and five (zero = bad, five = good) to evaluate the overall condition of the road.

The PASCO system, on the other hand, determines the extent of surface cracking and patching by obtaining continuous strips of photographs taken in the night with a slit camera. The rut depth is measured by a hairline projected at an angle and the projected image photographed by a pulse camera; and the roughness is determined either by measuring the movements of the wheel relative to the vehicle body or the distance by measuring between the surface and vehicle body with a laser beam and immediately plotting the information on a strip chart by computer. The resulting values are used by PASCO to compute Maintenance Control Index (MCI) values between 0 and 10 (0 = bad and 10 = good) as an overall estimate of the condition of the road.

Study Plan and Objectives

This study was undertaken to evaluate PASCO's automated system in relation to the methods employed by the Iowa DOT. Some seven different sections of roads in the vicinity of Ames were used for the comparison. Sections 1-3 involved segments of Interstate 35 with both portland cement and asphaltic cement concrete surfaces, various construction thicknesses, and base materials. These included one mesh-reinforced pavement, one joint-reinforced pavement, and one continuously reinforced pavement on various combinations of base and subbase materials. Two shoulder sections were also included for evaluation of the potential development of a shoulder data base for rehabilitation decisions. Multiple passes were made over each section in each driving lane and on the shoulder to provide sufficient data upon which to draw statistical conclusions for each type of data collected.

Sections 4 and 5 represented typical county construction methods with both asphalt and portland cement concrete surfaces and the introduction of transverse grooving of the surface in one instance. Speed limits of 45 mph were present on these sections and the reaction of the equipment to a railroad crossing was observed in one section.

Urban driving conditions were included in Sections 6 and 7 with each being a four-lane urban section with both portland cement concrete and asphaltic cement concrete over portland cement concrete surfaces in place. The effect of railroad crossings and stop-and-go situations was observed in the data from these locations.

Study Results

The results indicated a high correlation between the two PASCO methods in the measurement of roughness with 0.93 for the tracking wheel method and 0.84 for the laser method. The values obtained placed the repeatability performance in the 99% confidence level for all measurements except those taken by the laser. The laser measurements resulted in a 95% confidence level that can be improved upon with the use of computer analysis of the output.

Rut-depth correlations of 0.61 and cracking of 0.32 (70% confidence level) are attributed to the ability of the PASCO equipment to measure the entire cross profile and to measure all cracks under constant light and vertical viewing conditions. The equipment can measure each crack and patch carefully over the entire length of the test section, whereas the Iowa DOT method works more subjectivity and uses a sample one-half mile section to test. Rut depths measured by PASCO use the shoulder and the edges of the lane to measure total differences in elevation up or down rather than the current four-foot straight-edge method.

The overall longitudinal profile values (LPVs) of the Iowa DOT method and the Standard Deviation (SD) of roughness by the PASCO method seem to correspond. Additionally, the PSI rating by the Iowa DOT method and MCI by the PASCO method correspond well.

The data indicates that the PASCO organization operating with one unit and two to three operators can gather data as fast or faster than the Iowa DOT can with five vehicles and three to six persons to perform the two operations. The ability to operate in traffic with one vehicle versus several vehicles and with no personnel performing work on the pavement surface is an advantage in terms of safety. The ability of the PASCO unit to operate at night provides an additional benefit because it can maintain a constant speed through municipalities during data collection at night when traffic interference is reduced.

Cost Comparisons

The cost analysis of the data provided by both systems indicates that PASCO is capable of providing a comparable result with improved accuracy at a cost of $125-$150 or less per two-lane mile where large mileages of survey can be planned in advance. It can provide the Iowa

DOT with increased data collection accuracy and reliability and a visible record of pavement condition with no increase in program costs.

Accuracy of Measurements

PASCO provides the Iowa DOT with a system that can measure cracks 0.05 in. wide and patches 0.5 in. square or larger. Tracking wheel roughness measurements are within an accuracy of ±0.05 in., while the laser is capable of measuring to ±0.01 in. Since the Iowa DOT can currently measure roughness only within an inch, the PASCO system enhances accuracy.

Manual Condition Survey Methods Comparison

The results of the ROADRECON systems were evaluated against the requirements of three nationally developed manual methods of measuring pavement conditions that have been developed to date. They included the following:

1. Highway Pavement Distress Identification Manual for Highway Condition and Quality of Construction Survey (March 1979).
2. Pavement Condition Rating Guide (September 1985).
3. SHRP/LTPP Identification Manual (September 1986).

Each of these methods was developed for various purposes associated with the development of the Strategic Highway Research Program and a national pavement management data base. Each of the methods employs the use of photographs and verbal means to define the presence of the type of distress and its severity in common terms. The methods differ primarily in the magnitude of the physical measurements in defining severity. The majority of the distresses are measured by area or simply by their presence, both of which can be easily measured with photography, such as PASCO employs. The remaining distresses such as shoulder/lane dropoffs and faulting, rutting, and bleeding can be measured with the PASCO unit's use of artificial light, pulse camera, and slit camera operations. Lasers have the ability to measure faulting although it was not measured on this project. Crack width and lane shoulder separations can be measured to an accuracy of one-quarter to one-half inch in width by enlarging the photographs.

Future Equipment Requirements

With the PASCO system, work remains to reduce the time lag of one to five weeks involved in the film processing and analysis. This may be improved by processing the film in the United States or using stop-action video cameras and laser disk storage mediums. Recommendations regarding the improvement of the equipment include:

1. Potential use of video cameras and laser disk storage.
2. On-board computer editing of the data.
3. Collection of rut depth, roughness, cracking simultaneously.
4. Continued development of the laser measurement system.

Summary and Conclusions

The PASCO system represents a way of mechanizing the data collection process for the Iowa DOT at an affordable price without sacrificing the historical data collected by current methods. It provides an opportunity to free field and office personnel from crack and patch surveys for other more urgent duties. It also serves as a transition process from manual methods of data collection and analysis to automated objective data collection with analysis of pavement distress by a single trained observer. The goal is computer analysis of the pavement condition with quality control provided by the pavement management staff. Achieving this goal in turn will assist the Iowa DOT in removing much of the subjectivity from the condition analysis and in improving the objectivity of the information provided to top management for pavement rehabilitation decisions. The DOT should investigate the feasibility of obtaining the PASCO equipment or services and establishing a program to begin using the method to obtain and analyze the pavement condition of the primary highway system.

PASCO can aid the highway condition rating analysis at two governmental levels. As shown in this report, for rehabilitation plans it can provide visual and numerical data to states and local units of government, provide and inventory haul routes and detours, and provide necessary information for defense in legal suits. It can replace several pieces of equipment and personnel currently used to gather individual items of data with one-pass data collection under uniform environmental conditions.

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1. INTRODUCTION

When pavement condition is evaluated, all available information should be gathered regarding the surface of the road and the structural strength of the material used in road construction, so that a proper maintenance schedule can be developed. In the past, most such information was gathered manually; however, with the advent of computers and high technology, these procedures can now be automated.

The Iowa Department of Transportation (Iowa DOT) uses mainly manual procedures. The PASCO USA, Inc. system is fully automated to give surface condition information. The surface condition information, as used in this study, comprises roughness, cracking, patching, and rut depth.

The Iowa DOT determines cracking, patching, and rut depth by sending a crew to estimate and measure this information in the field. The Iowa DOT determines the roughness by a response type profilometer that is calibrated against a standard instrument, the CHLOE profilometer. Using these values, the Iowa DOT obtains a Present Serviceability Index (PSI) value that lies between zero and five (zero = bad, five = good) to evaluate the overall condition of the road.

The extent of cracking and patching of the road surface is determined with the PASCO system by obtaining continuous strips of photographs taken in the night with a slit camera; the rut depth is determined when a hairline is projected at an angle and the projected image is photographed by a pulse camera; and the roughness is measured either as the movements of the wheel are measured in Z directions with an accelerometer or as the distance is measured with a laser beam. The variation in Z is immediately plotted by a computer on a strip chart. Using these values, PASCO computes Maintenance Control Index (MCI) values between 0 and 10 (0 = bad and 10 = good) as an overall estimate of the condition of the road.

The objective of this study is to evaluate PASCO's automated system. In order to evaluate the system, seven different sections of roads in the vicinity of the Iowa DOT were evaluated with both the Iowa DOT and PASCO methods. The overall evaluation by both systems agreed fairly well. However, analysis of each individual component revealed that patching, cracking, and rut depth were measured more accurately by the PASCO method than by the Iowa DOT method. This discrepancy may exist because each patch and crack is carefully calculated by the PASCO method, whereas the Iowa DOT method works subjectively. The PASCO method of measuring rut depth uses the shoulder as a control, whereas the Iowa DOT method uses a four-foot straight edge to measure the rut depth. *The* Longitudinal Profile Values (LPVs) of the Iowa DOT method and the Standard Deviation (SD) of roughness by the PASCO method seem to correspond. Additionally, the PSI overall rating by the Iowa DOT method and MCI by the PASCO method correspond well.

The PASCO method appears to be the more cost and time efficient. It uses trained engineers both to collect the data and analyze them. However, the Iowa DOT method employs skilled technicians using manual methods to collect the data and trained engineers to analyze them.

2. DESCRIPTION OF IOWA DOT METHOD

The Iowa DOT defines the PSI of a road surface as

$$PSI = LPV - 0.01\ (C_{AC} + P)^{1/2} - 1.38\ (\overline{RD}^2) \tag{1}$$

for an asphalt surface and

$$PSI = LPV - 0.09\ (C_{PC} + P)^{1/2} \tag{2}$$

for concrete surfaces where LPV is a function of the roughness of the road and

C_{AC} = the number of square feet per 1000 square feet of asphaltic concrete exhibiting cracking.

C_{PC} = the number of square feet per 1000 square feet of portland cement pavement.

P = number of square feet per 1000 square feet of asphaltic concrete pavement exhibiting "alligator" or fatigue cracking.

RD = the mean depth of rutting, in inches, measured with a four-foot straight edge.

Thus, the PSI is made up of two values--LPV and the deduction for cracking, patching, and rut depth. The LPV is selected so that a maximum LPV is five when the roughness is zero; thus, the PSI value can reflect values of five, indicating excellent, to zero, indicating poor road condition.

The current Iowa DOT methods of obtaining values of roughness, cracking, patching, and rut depth are detailed in the Appendix A. A general description is provided in the following sections.

Roughness

Roughness can be defined as the deviation of the surface from a smooth profile, a constant-gradient longitudinal profile. Roughness is often defined in a number of ways:

1. $R = \text{inches per mile} = \dfrac{\sum_{i=1}^{n} y_i}{D}$

   where

   Y_i = deviation in inches from the smooth surface at point i (see Fig. 1)

   D = the distance in miles

   n = number of points

2. Standard deviation $SD = \sqrt{\dfrac{\sum_{i=1}^{n} (y_i - y_o)^2}{n - 1}}$

   where

   $y_o = \dfrac{\Sigma y_i}{n}$

3. Slope variance $SV = \dfrac{\Sigma(S_i - S_o)^2}{n - 1} = \dfrac{\Sigma S_i^{\ 2} - 1/n\ (\Sigma S_i)^2}{n - 1}$

   where

   S_i = slope at a point i (see Fig. 1).

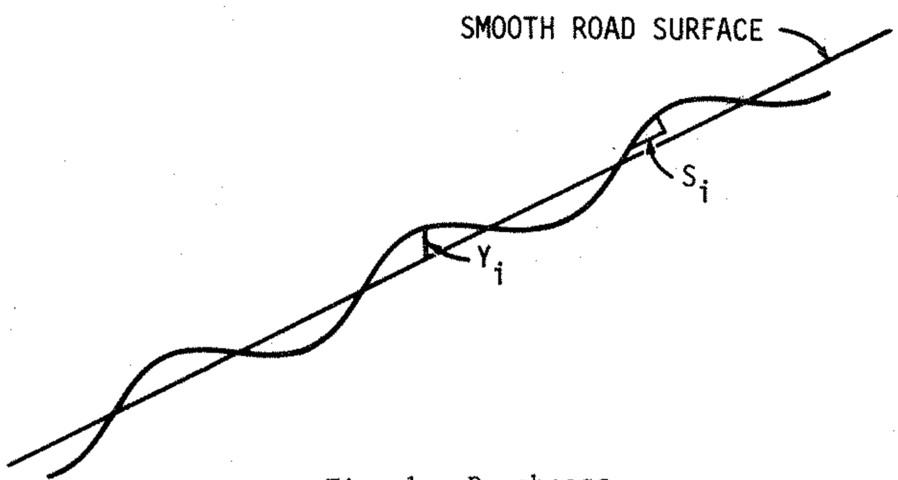


Fig. 1. Roughness.

The Iowa DOT uses the Bureau of Public Roads (BPR) roughometer to obtain the roughness in terms of inches of roughness per mile. The BPR consists of a single road wheel attached to an accumulating counter by a one-way clutch (see Fig. 2). As the wheel moves up and down while being towed, all movements in one direction are summed. Another counter records the number of revolutions of the tire so that distance traveled can be calculated (see the Appendix A).

The BPR readings are calibrated against a standard roughometer, CHLOE, to give the LPVs. The CHLOE consists of two units: a trailer unit, which carries the transducing mechanism, and the electronic computer, which gets the information from the transducer, does the necessary computation, and displays the results. Figure 3 shows the CHLOE, Fig. 4 shows the transducer, and Fig. 5 shows the computer. The slope transducer is equipped with two eight-inch road wheels attached to the pivot arm. The transducer provides a continual measure of the angle between the bar connecting the slope wheels and the arbitrary reference of the trailer unit. The values obtained by the CHLOE are not affected by possible change in the towing vehicle's suspension. Because the CHLOE is very sensitive, slopes are obtained at five mph, which is time consuming. With the slope value, S, the slope variance SV (which is the variance of the slope) is computed from

$$SV = \frac{\sum_{i=1}^{n} S_i^{\,2} - 1/n\left(\sum_{i=1}^{n} S_i^{\,2}\right)}{n - 1} = \frac{\sum_{i=1}^{n}\left(S_i - \frac{\Sigma S_i}{n}\right)^2}{n - 1}$$

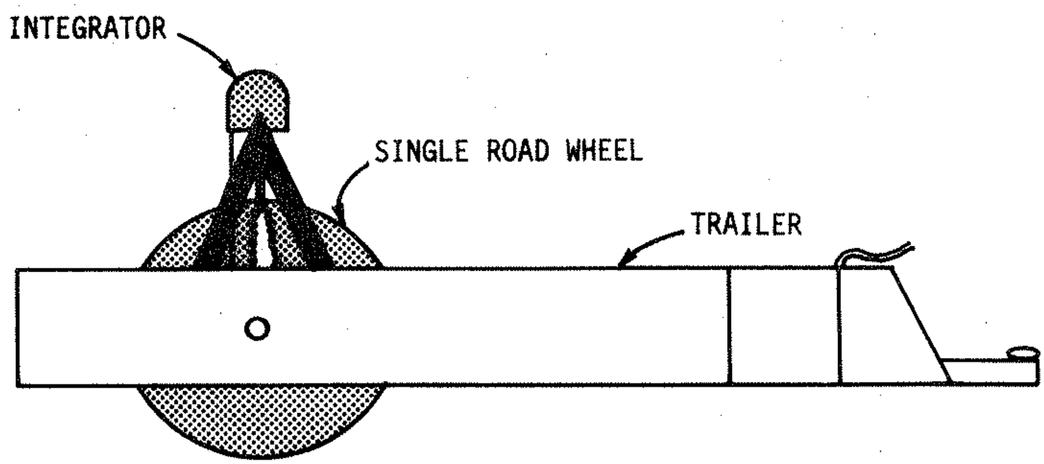


Fig. 2. BPR method.

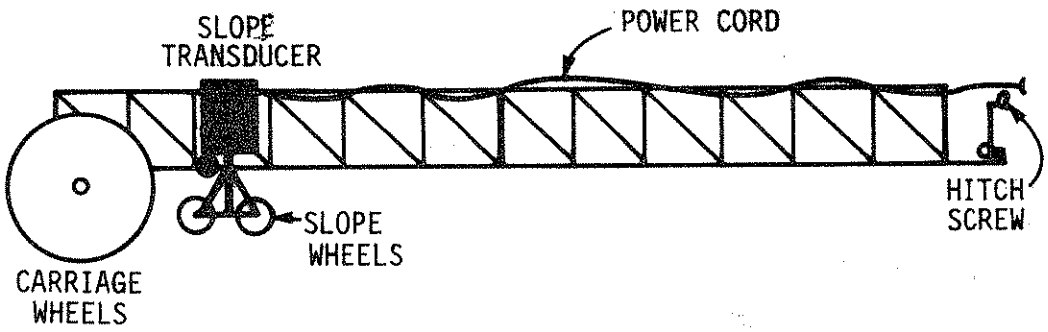


Fig. 3. CHLOE profilometer.

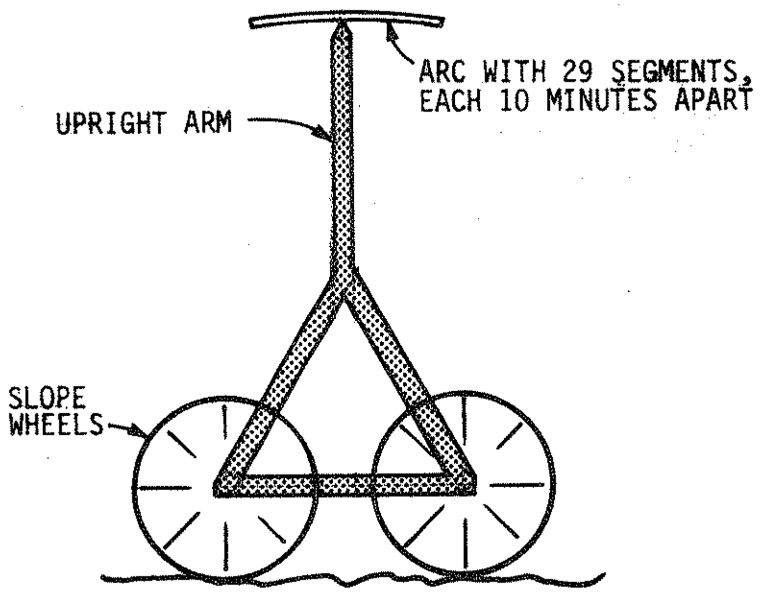


Fig. 4. Transduce r.

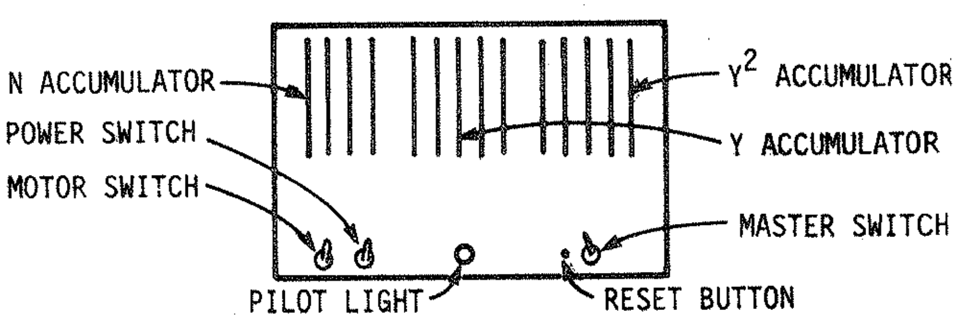


Fig. 5. Computer.

The slope variance is then used to obtain LPV from

$$LPV = 5.41 - 1.80 \text{ Log } (1 + SV) \text{ for concrete surface, and}$$

$$LPV = 5.08 - 1.90 \text{ Log } (1 + SV) \text{ for asphalt.}$$

The BPR roughometer, unlike the CHLOE, can be operated at 30 mph. However, the CHLOE is more accurate and therefore the BPR is calculated periodically against the CHLOE. A correlation equation, giving the LPVs for a given roughness in inches per mile (X) and obtained from the BPR roughometer reading, is then used. The current correlation equation used is

$$LPV = -9.154175 + 0.23721 X$$

Table 1 shows the LPVs corresponding to X values from the BPR roughometer as interpolated with this equation. Table 2 shows a typical BPR roughometer reading.

Cracking, Patching, and Rut Depth

The method of determining the cracking, patching, and rut depth by the Iowa DOT is presented in detail in the Appendix A. The Iowa DOT uses crews of three to five persons to observe and record the extent of cracking, patching, and rut depth as defined below:

Cracking (asphalt)

C_{AC} = number of square feet per 1000 square feet of asphaltic concrete pavement exhibiting "alligator" or fatigue cracking.

Table 1. Longitudinal profile values (LPVs) corresponding to X values from the BPR roughmeter (as interpolated using with equation shown).
-9.154175 + 0.2372100*X
DATE 07/02/86

BPR RR	LPV FOR AC	LPV FOR PC	BPR RR	LPV FOR AC	LPV FOR PC
52	4.892		290	1.667	2.241
54	4.612		300	1.634	2.209
56	4.403	4.819	310	1.601	2.179
58	4.236	4.662	320	1.570	2.150
60	4.097	4.531	330	1.541	2.122
62	3.978	4.419	340	1.512	2.094
64	3.874	4.321	350	1.484	2.068
66	3.782	4.234	360	1.457	2.043
68	3.699	4.156	370	1.431	2.018
70	3.623	4.084	380	1.406	1.994
72	3.554	4.019	390	1.381	1.971
74	3.490	3.959	400	1.357	1.949
76	3.431	3.903	410	1.334	1.927
78	3.376	3.851	420	1.312	1.906
80	3.324	3.802	430	1.290	1.885
82	3.275	3.756	440	1.268	1.865
84	3.229	3.712	450	1.247	1.845
86	3.185	3.671	460	1.227	1.826
88	3.144	3.632	470	1.207	1.807
90	3.104	3.595	480	1.188	1.789
92	3.066	3.559	490	1.169	1.771
94	3.030	3.525	500	1.150	1.754
96	2.996	3.493	510	1.132	1.737
98	2.962	3.461	520	1.115	1.720
100	2.930	3.431	530	1.097	1.704
105	2.856	3.361	540	1.080	1.688
110	2.787	3.296	550	1.064	1.672
115	2.724	3.237	560	1.047	1.657
120	2.665	3.181	570	1.031	1.641
125	2.610	3.129	580	1.015	1.627
130	2.558	3.081	590	1.000	1.612
135	2.510	3.035	600	0.985	1.598
140	2.464	2.992	620	0.955	1.570
145	2.420	2.951	640	0.927	1.543
150	2.379	2.912	660	0.899	1.517
155	2.340	2.875	680	0.873	1.492
160	2.302	2.839	700	0.847	1.468
165	2.266	2.806	720	0.822	1.444
170	2.232	2.773	740	0.798	1.421
175	2.199	2.742	760	0.774	1.399
180	2.167	2.712	780	0.751	1.378
185	2.136	2.683	800	0.729	1.357
190	2.107	2.655	820	0.707	1.336
195	2.078	2.628	840	0.686	1.316
200	2.051	2.602	860	0.665	1.297
210	1.998	2.553	880	0.645	1.278
220	1.949	2.506	900	0.625	1.259
230	1.902	2.462	920	0.606	1.241
240	1.858	2.421	940	0.587	1.223
250	1.816	2.381	960	0.569	1.206
260	1.776	2.344	980	0.551	1.189
270	1.738	2.308	1000	0.533	1.172
280	1.702	2.274	1020	0.516	1.156

Table I. Continued.

BPR
-9154175 + 0.2372100*X
DATE 07/02/86

BPR RR	LPV FOR AC	LPV FOR PC
1040	0.499	1.140
1060	0.483	1.125
1080	0.467	1.109
1100	0.451	1.094
1120	0.435	1.080
1140	0.420	1.065
1160	0.405	1.051
1180	0.390	1.037
1200	0.375	1.023
1220	0.361	1.010
1240	0.347	0.997
1260	0.333	0.984
1280	0.320	0.971
1300	0.306	0.958
1350	0.274	0.928
1400	0.243	0.898
1450	0.213	0.870
1500	0.184	0.843
1550	0.156	0.816
1600	0.128	0.791
1650	0.102	0.766
1700	0.077	0.742
1750	0.052	0.719
1800	0.028	0.696
1850	0.005	0.674
1900		0.653
1950		0.632
2000		0.612
2050		0.592
2100		0.572
2150		0.554
2200		0.535
2250		0.517
2300		0.500
2350		0.483
2400		0.466
2450		0.449
2500		0.433
2550		0.418
2600		0.402
2650		0.387
2700		0.372
2750		0.357
2800		0.343
2900		0.315
3000		0.288
3100		0.262
3200		0.237
3300		0.213
3400		0.189
3500		0.166
3600		0.144
3700		0.122
3800		0.101
3900		0.080
4000		0.060
4100		0.041
4200		0.022
4300		0.003

Table 2. Typical BPR roughmeter readings.

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
AMES LABORATORY

ROAD ROUGHNESS FIELD REPORT

Lab. No. RR____ Report Date 7-18-86 County Story

Proj. Miles____ Year Built____ Road No.____

Contractor____ Project No.____

Location Duff South 4th to S 16th   Asph.Conc.__ P.C. Conc.__   A.C. Resurf__ Slip Form__ Fixed Form__

Date Tested 7-18-86 Weather Clear

Test Observers Twohey - Maass

Terminus	Sect No.	P C	A C	Length Miles	South Rev.	R.R.	Roughness In/Mi.	North Rev.	R.R.	Roughness In/Mi.
Outside Lane Outside Track	1				612	99	121	606	142	176
	2				610	94	116	607	140	173
	3				610	100	123	611	139	171
Outside Lane Inside Track	1				611	84	103	609	106	131
	2				612	84	103	609	107	132
	3				611	83	102	609	105	129
Inside Lane Outside Track	1				611	90	110	610	104	128
	2				610	87	107	609	105	129
	3				611	86	106	610	107	132
Inside Lane Inside Track	1				608	83	102	610	103	127
	2				609	84	103	611	105	129
	3				607	84	104	611	99	122

Miles Measured____ Ave. ____ Ave. ____

Cracking (concrete)

C_{PC} = number of linear feet of cracking per 1000 square feet of portland cement pavement. Only those cracks that are open to a width of 1/4 in. or more along half their length or those that are sealed are to be included.

Patching

P = number of square feet per 1000 square ft repaired by skin (widening joint strip seal) or full depth patching.

Rut Depth

RD = mean depth of rutting, in inches, measured with a four-foot straight edge.

The crew drives on the shoulder if possible, estimates the areas of cracking and patching, and records them on a work sheet. Table 3 is a typical work sheet. The rut depth is measured at every 0.05 mi for asphalt pavement, and one set of readings is taken at the beginning and end of a half-mile section of concrete pavement.

The area of cracking in asphalt pavement is totaled and divided by the area of the test section in thousands of square feet to obtain C_{AC} for use in Eq. (1). The number of cracks and 1/2 cracks (divided by 2) are totaled and multiplied by the width of the roadway and divided by the area of the test sections in thousands of square feet to use (C_{PC}) in Eq. (2). The area of patching is totalled and divided by the area of the test section in thousands of square feet to obtain P for Eq. (1) or (2). The rut depth measurements are totaled and averaged to obtain RD in Eq. (1).

Table 3. Iowa DOT work sheet.

WB Lincolnway & Duff to Lincolnway + Grand #7

CRACK AND PATCH SURVEY REPORT SHEET (P. C.)

Co No 85 | Hwy. Sys. U (I-Interstate U-U.S. S-Iowa C-County) | Route 0069

Beg Mp 114.00 | End Mp 116.00

Beg Mp of 1/2 Mi Test 115.45 | End Mp of 1/2 Mi Test 115.95

1 Date 070186 | Width 24

Survey Conducted By Gramling

Total No. of Cracks 0071
(1/4 wide over 1/2 crack length or sealed)

Total No. of Half Cracks 0049

Total Sq. Ft. of Patched Area *(Full Depth or Surface)* 06602 (138x24)+(24x45)+48+10+60+80+3(12x24)+48+60+3+10+36+10+100 60+12+21+400+48+8+48+36+36 12+140+144+12+232+144+36+10

D - Cracking Occurrence Factor *(0 to 5)* 2

2 FAULTING AND RUT DEPTH *(10 Locations 0.05 Miles Apart)*

(Driving Lane For 4 Lane Highways)

1 Ft From Edge 0.12 | 0.00 | 0.02 | 0.07 | 0.05 | 0.13 | 0.55 | 0.32 | 0.42 | 0.15

OWT 0.08 ... 0.00

Outside U B

IWT 0.19 ... 0.02

(Passing Lane For 4 Lane Highways)

IWT 0.00 ... 0.00

Inside U B

OWT 0.00 ... 0.00

1 Ft From Edge 0.00 | 0.00 | 0.03 | 0.30 | 0.00 | 0.09 | 0.12 | 0.08 | 0.38 | 0.

Shoulder Width N/E 09 *(Driving Lane)* S/W 00 *(Passing Lane)*

3 Remarks

3. DESCRIPTION OF PASCO METHODS

The history of the PASCO Road Survey (PRS) System is an indication of how Japanese engineers have worked to answer the same data questions that we are trying to answer today in the United States. The PRS system is their answer to objective collection and analysis of data on pavement conditions for use by government officials to make pavement rehabilitation and design decisions.

Identification or model numbers relate the historical development of the machine and the story of the step-by-step solutions to problems. The ROADRECON-70 got its start in 1965 and was the first patented automatic continuous road surface photographic recorder in Japan in 1970. ROADRECON-75, for the measurement of rut depth, was developed to meet the second measurement of distress noted by the engineers and was patented. A government need for the measurement of longitudinal profile resulted in the contract for the development of ROADRECON-77. Between 1977 and 1985 the PASCO agency developed the software technology to analyze the film and the use of laser technology. ROADRECON-85 has resulted from this work in laser technology to date. Efforts are continuing to develop retrieval systems for laser-disk-based pavement condition data/images.

Prior to 1963, PASCO conducted manual pavement distress surveys in a manner similar to that of the Iowa DOT. They noted the variations in distress measurements resulting from the position of the sun and the observer. This often resulted in differing views on the presence of a particular distress, its extent, and its severity. Problems in the observation results were noted during windshield surveys at low speeds (5-10 mph). Subjectivity was introduced when more than one person observed and recorded the distress on consecutive or identical sections of pavement. Safety was always a problem when personnel were required to walk the pavement to identify the distress type, extent, and severity. As a result PASCO created the PRS hardware and software to provide pavement management support.

The ROADRECON system has several options to provide a tailored approach to highway condition measurement requirements. The various options are summarized in Table 4. The distress measurements associated with each option are shown in Table 5.

The objective of the PASCO method is to determine the values of cracking, patching, rut depth, and roughness so that the present condition of the road can be evaluated and the future condition predicted. The PASCO method computes an MCI from the equation

$$MCI = 10 - 1.48\ CR^{0.3} - 0.29\ RD^{0.7} - 0.47\ SD^{2} \qquad (3)$$

or

$$= 10 - 1.51\ CR^{0.3} - 0.30\ RD^{0.7} \text{ (if roughness is not available)}$$

or

$$= 10 - 2.23\ CR^{0.3} \text{ (using only cracking ratio)}$$

or

$$= 10 - 0.54\ RD^{0.7} \text{ (using only rut depth)}$$

Table 4. Performances of ROADRECON field survey equipment series.

ROADRECON	-70	-75	-77	-77B	-85	-85B
Survey items	Surface distress (cracking, pot hole, patching, spalling, etc.)	Cross profile (rutting, drop off, shoulder slope, etc.)	Longitudinal profile and roughness	Longitudinal profile and roughness	Longitudinal profile and roughness	Longitudinal profile, roughness and rutting
Sensor	35mm slit camera	35mm pulse camera	Tracking wheel, differential	Laser sensor	3 laser sensors	3 laser sensors
Light source	10 halogen lamps	Hairline projector with strobe tube	Transformer and accelerometer	Infra-red laser	Infra-red laser	Infra-red laser
Measuring width	5.0 m (1 lane)	5.0 m (1 lane)	Outside wheel path	Outside wheel path	Outside wheel path	Both wheel paths and lane center
Measuring speed	0 - 80 km/h	0 - 80 km/h	0 - 60 km/h	0 - 80 km/h	0 - 80 km/h	0 - 80 km/h
Measuring interval	Continuous	0.1 - 99.9 m (variable)	0.1 - 99.9 m (variable) and continuous on paper chart	0.1 - 99.9 m (variable) and continuous on paper chart	0.1 - 99.9 m (variable)	0.1 - 99.9 m (variable) and continuous on paper chart
Output	35mm cine film	35mm cine film	Pen recorder and cassette tape	Pen recorder and cassette tape	Cassette tape and CRT display	Pen recorder and cassette tape
Maximum data storage capacity	60 km/roll (1,000 ft/roll)	120 km/roll (400 ft/roll and 20 m interval)	80 km/cassette on automatically shiftable dual cassette deck	80 km/cassette on automatically shiftable dual cassette deck	80 km/cassette on automatically shiftable dual cassette deck	80 km/cassette on automatically shiftable dual cassette deck
Operating environment	Day and night	Night	Day and night	Day and night	Day and night	Day and night
Accuracy	Cracking width 1 mm (resolution by cracking test chart)	Rut depth ± 2 mm	± 1 mm	± 1 mm	± 1 mm	± 1 mm
Recording scale	1/200 on original negative film	1/200 on original negative film	1/200 on paper chart	1/200 on paper chart	---	1/200 on paper chart

Note: 1 km/hr = 0.625 mi/hr
1 mm = 0.04 in.

Table 5. Surface distress survey items covered by ROADRECON series.

Distress	ROADRECON Series					
	-70	*-75	-77	-77B	-85	-85B
<u>Asphalt Surface</u>						
2.1 Alligator or fatigue cracking	X	O				
2.2 Bleeding	X	O				
2.3 Block cracking	X	O				
2.4 Corrugation	O		X	X		X
2.5 Depression	O	O	O	O		O
2.6 Joint reflection cracking from PCC slab	X					
2.7 Lane/shoulder dropoff or heave	X	X				
2.8 Lane/shoulder separation	X	O				
2.9 Longitudinal/transverse cracking (non-PCC slab joint reflective)	X/X	O/				
2.10 Patch deterioration	X					
2.11 Polished aggregate	O					
2.12 Potholes	X					
2.13 Pumping and water bleeding	X					
2.14 Raveling and weathering	X					
2.15 Rutting		X				O
2.16 Slippage cracking	X					
2.17 Swell	O			O		O
<u>Jointed Plain/Reinforced Concrete</u>						
3.1 Blow-up	O		O	O		O
3.2 Corner break	X					
3.3 Depression	O		O	O		O
3.4 Durability ("D") cracking	X	O				
3.5 Faulting or transverse joints and cracks	O			O		O
3.6 Joint load transfer system associated deterioration	X			O		O
3.7 Joint seal damage of transverse joints	X					O
3.8 Lane/shoulder dropoff or heave	O	X				
3.9 Lane/shoulder joint separation	X	O				
3.10 Longitudinal cracks	X	O				
3.11 Longitudinal joint faulting	O	X				
3.12 Patch deterioration	X					
3.13 Patch adjacent slab deterioration	X					
3.14 Popouts	X					
3.15 Pumping and water bleeding	X					
3.16 Reactive aggregate durability distress	X					
3.17 Scaling, map cracking and crazing	X					
3.18 Spalling (transverse/longitudinal joints)	X/X	/O				O
3.19 Spalling (corner)	X					
3.20 Swell	O	O				O
3.21 Transverse and diagonal cracks	X					
<u>Continuously Reinforced Concrete</u>						
5.1 Asphalt patch deterioration	X					
5.2 Blow-up	O		O	O		O
5.3 Concrete patch deterioration	X					
5.4 Construction joint distress	X					
5.5 Depression	O		O	O		O
5.6 Durability ("D") cracking	X	O				
5.7 Edge punchout	X					
5.8 Lane/shoulder dropoff or heave	O	X				
5.9 Lane/shoulder joint separation	X	O				
5.10 Localized distress	X					
5.11 Longitudinal cracking	X	O				
5.12 Longitudinal joint faulting	O	X				
5.13 Patch adjacent slab deterioration	X					
5.14 Popouts	X					
5.15 Pumping and water bleeding	X					
5.16 Reactive aggregate distress	X					
5.17 Scaling, map cracking and crazing	X					
5.18 Spalling	X					
5.19 Swell	O			O		O
5.20 Transverse cracking	X					

*ROADRECON-75 covers items by sampling method.

†"X" indicates items well covered and "O" indicates items covered with other ROADRECON series.

where

CR = *cracking ratio* (%)

RD = rut depth (mm)

SD = longitudinal roughness (mm)

Thus MCI varies from 0 (poor) to 10 (very good). PASCO uses the ROADRECON-70, a 35-mm slit camera, to take continuous photographs of the road and then to interpret the photograph and measure the area to obtain the CR. The RD is measured on the photograph of a hairline projected at an angle taken by a pulse camera, ROADRECON-75. The longitudinal roughness (SD) is measured either by ROADRECON-77 or by ROADRECON-85. The ROADRECON-77 system uses a tracking wheel fitted with a differential transformer and a Servo accelerometer to measure longitudinal roughness, whereas the ROADRECON-85 uses three noncontact GA-AS diode laser sensors to measure longitudinal profile and roughness.

Slit Camera: The ROADRECON-70

The ROADRECON-70 system uses a 35-mm slit camera to obtain continuous-strip photography of the driving lane. The camera's slit aperture is 1.08 in. (27 mm) long and can vary in width from 0.004 in. to 0.04 in. (0.1 mm to 1.0 mm). The lens has a focal length of 0.58 in. (14.5 mm) with F/3.5. (See Figs. B.1 and B.2.)

The camera is mounted on a boom on top of the survey vehicle, about 2.9 m above the ground. This setup results in a photographic scale of 1:200. Since the slit length is about 1.08 in. (27 mm), the photographs cover over 5 m of road width. The film speed and camera aperture size are synchronous with the vehicle speed to produce a continuous strip of photographs with the arrangement shown in Fig. B.3. With a standard 1000-foot roll of film, 37.5 mi (60 km) of roadway can be photographed. This system can be operated at speeds between 44 and 50 mph (70 and 80 km/h). The system, which can operate day or night, uses a bank of 10 halogen lamps mounted under the bumper for constant illumination.

The film is processed by use of an automatic film processor (see Fig. B.4). The processed positive film is projected onto an electronic digitizer (see Fig. B.5) by use of a ROADRECON film digitizer. A key is used to interpret the projected image subsection by subsection for cracks and patches (see Figs. B.6 and B.7). The projected image is enlarged ten times. The area of the interpreted patches and cracks is measured by the grid cell system (a grid system is overlaid on the projected area and the area is obtained by counting the number of square cells covering the crack). Since the subsection is about 20 ft for asphalt (or the size of a slab for concrete), use of a key to interpret the patches and cracks data results in an unbiased estimate. The CR in Eq. (3) is then given by

$$\text{CR} = \text{The crack ratio} = \frac{\text{Length of crack (m)} \times 0.3 \text{ m} \times 100}{\text{Total area (m}^2\text{)}}$$

$$\text{or} = \frac{\text{Crack area (m}^2\text{)} \times 100}{\text{Total area (m}^2\text{)}}$$

Use of the ten-times enlargement allows cracks of 0.04 in. (1 mm) or wider to be identified. Thus, using a grid cell of 0.02 in. × 0.02 in. (0.5 mm × 0.5 mm), we can measure the crack area with an accuracy of $\pm(200 \times 1/10 \times 0.5)^2 = \pm 0.4$ in.^{2} (± 1 cm^2). Figure 6 illustrates the crack digitizing method.

Pulse Camera: The ROADRECON-75

The ROADRECON-75 system uses a 35-mm pulse camera and a hairline projector strobe light to photograph rutting wave patterns.

Figure 7 shows the projection of a hairline on the cross section of a road. If there is no rutting wave pattern, the hairline will be projected as a straight line SS'. However, if there is a rutting pattern LHM present, then the hairline at the high point H will be projected as H_1 and at the low point L will be projected as L_1. The distance D_1 of H_1 from SS' is proportional to the height of rutting HH_1 and distance D_2 of L_1 from SS' is proportional to the depth of the rutting. Now if the projected line is photographed by a vertical camera (see Fig. 8) directly above the line SS', then the hairline at H will be imaged at h and the hairline at L will be imaged at 1. If p is the principal point of the camera, then ph = d_1 and pl = d_2 can be measured accurately using a comparator (photogrametric instrument used to measure x-y coordinates on a photograph to an accuracy of one micron). Then, the distance

$$D_1 = \frac{H}{f} d_1$$

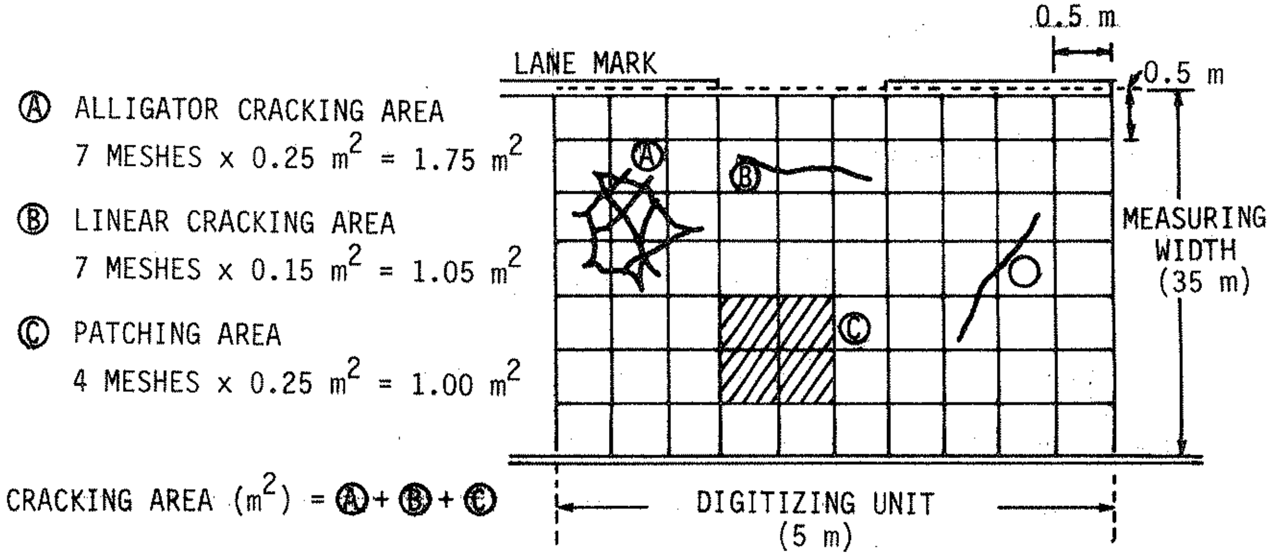


Fig. 6. Crack-digitizing method.

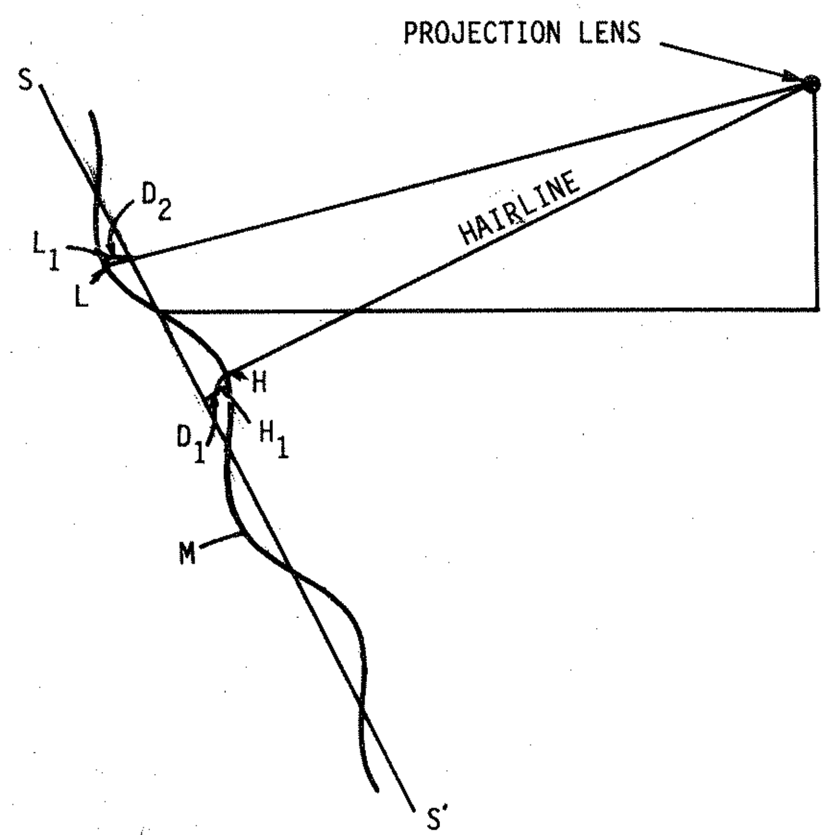


Fig. 7. Cross section of rutting wave pattern.

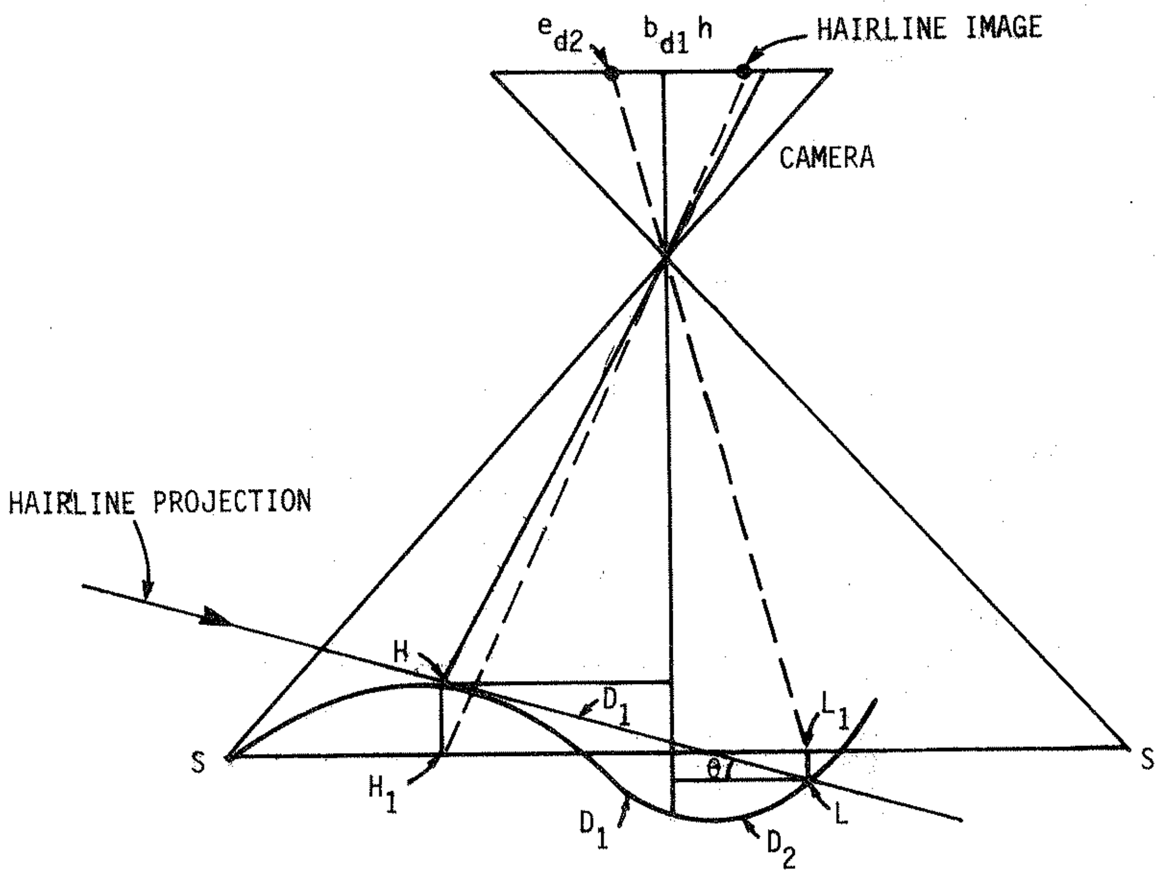


Fig. 8. ROADRECON-75.

and

$$D_2 = \frac{H}{f} d_2$$

where

f = focal length of the camera

H = height above mean ground

The rut height = $HH_1 = D_1 \tan \theta$.

The rut depth = $LL_1 = D_2 \tan \theta$.

Therefore, the total rut depth

$$RD = (D_1 + D_2) \cdot \tan \theta$$

$$= \frac{H}{f} (d_1 + d_2) \cdot \tan \theta$$

$$= S \tan \theta \, (d_1 + d_2)$$

where

S = the scale of the photo.

In the ROADRECON-75 system the strobe light is mounted on the bumper of the survey vehicle and projects the hairline at an angle $\theta = 26° \; 33$ min., such that $\tan \theta = 1/2$. The camera, mounted on a boom on top of the vehicle, photographs the lane in which the vehicle is driving (see Fig. 9). The camera is aimed straight down so any rutting is represented by a wave pattern in the hairline. The focal length of the camera, f = 0.6 in. (15 mm), and the height of the camera above the ground, H = 120 in. (3000 mm), result in a scale for the photograph of S = 200. Thus, the total rut depth = $200(d_1 + d_2)/2$, and if d_1 and d_2 are measured to an accuracy of ±0.0002 in. (±0.005 mm) by a comparator (or to an accuracy ±0.008 in. (±0.02 mm) on a digitizing tablet and

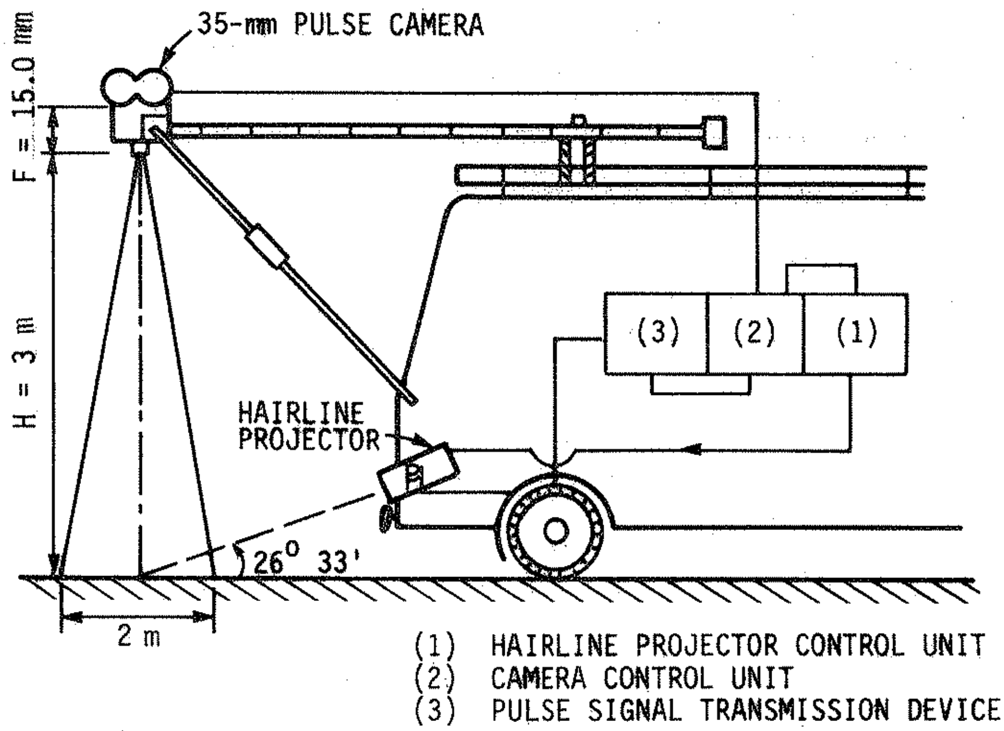


Fig. 9. ROADRECON-75 for rutting survey.

ten times enlargement imagery), the rut depth RD can be determined to an accuracy of ±0.04 in. (±1 mm).

This system can operate only at night (because daytime lights obstruct the hairline projection) at speeds between 0 and 50 mph (80 km/h). Both the strobe light and the camera shutter are triggered at given intervals of pavement travel. Intervals between 4 in. (0.1 m) and 333 ft (99.9 m) of pavement travel can be selected.

The camera has a maximum frame rate of ten frames per second in the pulse mode. The exposure time is about 1/64 sec. The film magazine has a loading capacity of 400 ft of film so that in the case of photographing at a regular interval of 67 ft (20 m), for example, approximately 62.5 mi (100 km) can be covered by one magazine load of film.

Tracking Wheel: The ROADRECON-77

The ROADRECON-77 uses a tracking wheel to measure longitudinal roughness of a road surface. The roughness is measured by a differential transformer and a Servo accelerometer attached to the tracking wheel. The tracking wheel is arranged so that it measures the roughness in the right wheel track of the lane in which the survey vehicle is driving (see Fig. 10). The accelerometer, attached to the tracking wheel or profile detector, measures the vertical acceleration and feeds the information to an on-board computer. The computer performs the necessary integration to determine the vertical displacement

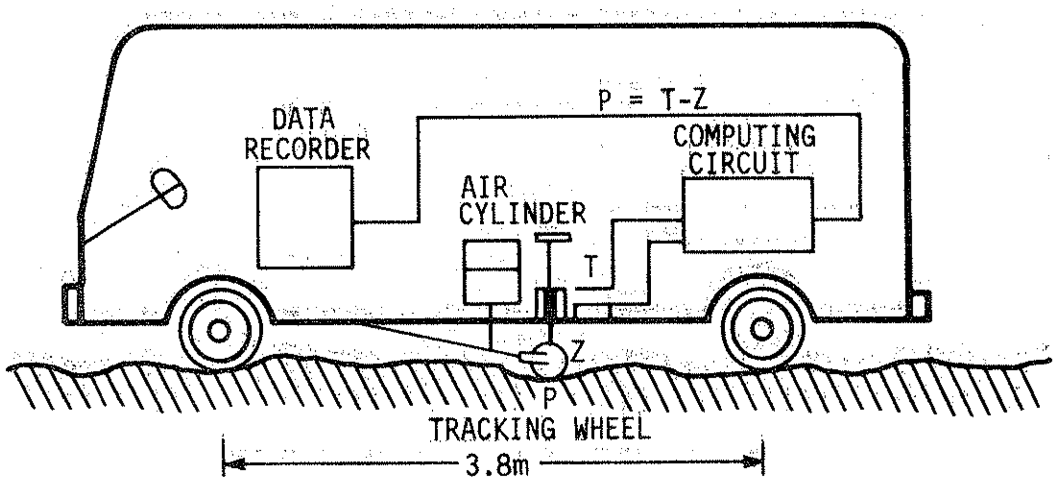


Fig. 10. ROADRECON-77 for evenness survey.

$$z = \int(\int a_z dt)\ dt = \Sigma a_{zi} dt^2$$

where a_z is the acceleration and dt is the time interval. In road roughness, R = T - Z, T is the total displacement of the vehicle and road, which the differential transformer computes. The roughness R is then plotted on a chart and also saved on computer cassette tape. By using the proper encoder, the speed and the distance traveled by the survey vehicle are also fed to the on-board computer, which saves this information on the cassette tape and also plots it on the paper chart (see Figs. B.8 and B.9). The computer also computes the total cumulative roughness (TCR) value where $TCR = \Sigma \left| R_i - R_{i+1} \right|$. The tick marks are made on the paper chart to indicate every 10 mm accumulation of TCR. Thus, total roughness between distances can be directly read on the paper chart. The longitudinal roughness, SD, in Eq. (3) is then obtained by

$$SD = \sqrt{\frac{\Sigma\ (R_i - \bar{R})^2}{n - 1}}$$

where

$$\bar{R} = \frac{\Sigma R_i}{n}$$

The R_i values saved on the cassette tape can be used to compute SD. Alternately, the ROADRECON-77 can be calibrated against a standard profilometer so that the correlation equation between the two systems can be determined. The TCR value and the correlation equation can then be used to determine the SD values.

The ROADRECON-77 can operate day or night at speeds between 0 and 40 mph. One cassette tape can contain data on 80 mi of roadway. The scale of the pen chart can be set at 1:100, 1:200, 1:400, or 1:500. The accuracy of the system is ±0.04 in. (±1 mm).

Laser: The ROADRECON-85B

The ROADRECON-85B uses three noncontact Ga-As diode laser sensors to measure roughness. The lasers are mounted on the bumpers of the survey vehicle, one over each wheel and one centered between them.

As the vehicle travels along the road, the lasers are triggered at a given interval of pavement travel. The laser diode, in the Optocator, emits a nonparallel beam of invisible infra-red (IR) light via a lens system. The laser beam triggered at a particular instant hits the surface of the road, and the diffused or scattered beam enters the detector via a lens system (see Fig. B.10). The lens of the detector focuses a spot image on a unique semi-conductor, an analog linear position detector. Here, the controllers for the noncontact laser measure the distance, r, of the spot image from the center of the detector and compute distance, x, between the vehicle and road surface

$$x = x_o \pm r$$

where x_o is the distance corresponding to the center of the detector. The controller of the laser provides the distance (x) information to the input/output controller of the computer. The encoder attached to the wheel of the survey vehicle communicates the distance, D, traveled by the survey vehicle to the I/O controller. The system control then plots these data on a chart in real time and also saves them on a tape cassette for future use (see Fig. B.11). The variation in x gives the roughness of the ride. The SD in Eq. (4) is then computed from

$$SD = \sqrt{\frac{\Sigma (X_i - \bar{X})^2}{n - 1}}$$

The system can operate day or night at speeds between 0 and 80 km/h. The laser can be triggered at intervals between 4 in. (0.1 m) to 33 ft (9.9 m). One cassette tape can contain data for 50 mi (80 km) of roadway. The resolution of the laser sensor is about 0.02 in. (0.4 mm).

4. COMPARISON OF PASCO AND IOWA DOT METHODS

In order to judge the PASCO method of evaluating the surface condition of the road, we decided to survey the surface of seven sections, each approximately one mile in length, in the vicinity of the Iowa DOT (see Fig. 11). The sites represent the various pavement and traffic conditions that the Iowa DOT actually encounters in rehabilitating and maintaining the primary road system. The sites are briefly discussed below.

1. Interstate 35 northbound lanes (two lanes, passing and driving) from mile post 103 to 104. This 10-in., mesh-reinforced portland cement concrete pavement with 76.5 ft joint spacings was constructed in 1965 on 4 in. of granular subbase and 8 in. of asphalt treated base and is used as an approach to a weigh-in-motion bridge.

2. Interstate 35 northbound lanes from mile post 114 to 115. This section of 10-in., joint-reinforced portland cement concrete pavement with 20 ft joint spacings was reconstructed in 1984 on 6 in. of recycled portland cement concrete. A reconstructed asphalt concrete shoulder is also included in the evaluation. Part of this section is used by Iowa DOT in their annual evaluation of the road profile measuring equipment.

3. Interstate 35 southbound lanes from mile post 115 to 114. This section contains 8-in. continuously reinforced portland cement concrete constructed in 1967 on four inches of granular subbase and eight inches of asphalt-treated base. Various areas of the driving surface were overlaid with asphaltic concrete in 1984 in conjunction with maintenance operations. The asphalt shoulders, also included in the evaluation, are in varying stages of distress.

4. Dayton Road between Lincoln Way and 13th Street in Ames. This section was constructed of a 4-in. granular subbase and a 6-in. rolled stone base and was surfaced with three inches of asphaltic concrete in 1959. It was sealcoated in 1965 and resurfaced with two inches of asphaltic concrete in 1968 and sealed in 1980. The surface offers varying amounts of distress to measure including a railroad crossing. This city street has a 45 mph speed limit.

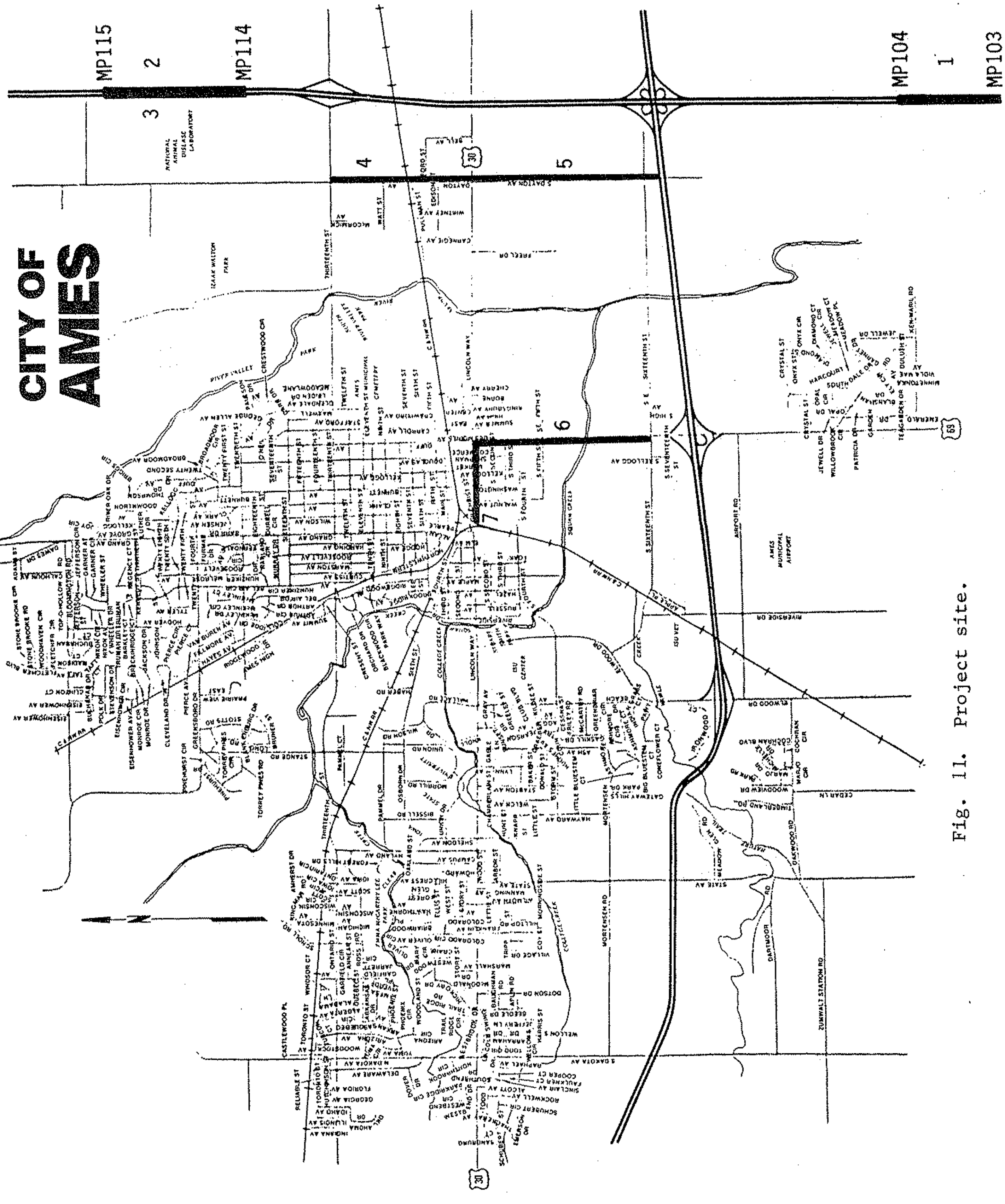


Fig. 11. Project site.

5. Dayton Road between Lincoln Way and U.S. Highway 30. This 8-in. portland cement surface constructed in 1981 shows relatively little deterioration and is in a 45 mph speed zone.

6. Duff Avenue between South 16th and south 4th Streets in Ames. This pavement is made up of several underlying components. The original pavement of two lanes was placed in 1929 as a thickened edge pavement with depths of 7 inches at center line and 10 inches at the edges. In 1948 the pavement was widened to two 12-ft lanes and overlaid with asphalt. The current asphalt concrete surface is the result of an additional widening to 49 ft with curbs and an overlay of the entire surface in 1963. The resulting surface is showing varying amounts of distress. The section includes a bridge crossing and a change in speed limit from 45 mph to 25 mph.

7. Lincoln Way between Duff and Grand Avenue. This section of 8-in. portland cement concrete placed in 1952 allows for the study of a portland cement concrete surface in varying stages of distress including patching. It also includes railroad crossings and a number of traffic signals. The posted speed limit for this section is 25 mph.

Iowa DOT Observations

The Iowa DOT collected the necessary data, patching, cracking, roughness (LPV), and rut measurements to compute the PSI values on all seven sections.

The BPR roughometer was used to determine the LPV values. On June 3, 1986, one pass was run on each wheel track (two per lane) of Sections 1, 2, and 3. On June 5, 1986, one pass was run on the outside shoulders of Sections 2 and 3. On July 18, 1986, three passes were run in each wheel track of Sections 4, 5, 6, and 7. Using the current correlation table (BPR method versus LPVs), the LPVs corresponding to the BPR method were obtained (see Table 6). Columns 1-3 of Table 6 identify each test section by number, location, and type of pavement. The lane being tested is shown in Column 4 (Lane); for example, the outside lane

Table 6. Summary of longitudinal profile values (LPVs) with BPR method.

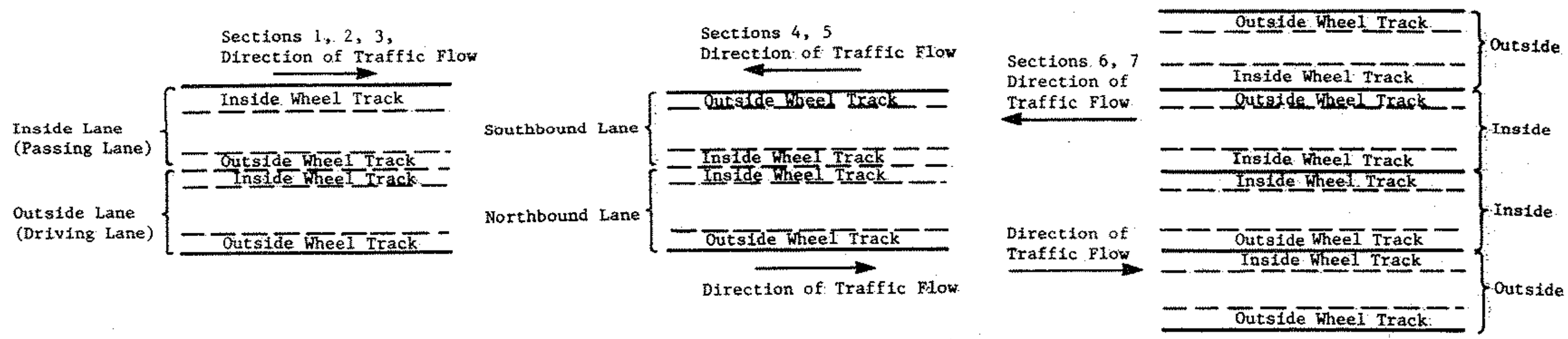
Section	Description	Type	Lane	Wheel Track	Revolutions	Revs./Mile	Roughness Reading	BPR Road Roughness	LPV
1	Interstate 35, 2 northbound lanes between MP 103 and 104	Portland cement (PC)	outside	outside	744	750	76 in./mi	77 in./mi	3.87
				inside	744		76 in./mi	77 in./mi	3.87
			inside	outside	744		69 in./mi	70 in./mi	4.08
				inside	744		75 in./mi	76 in./mi	3.90
2	Interstate 35, 2 northbound lanes and shoulders between MP 114 and 115	Portland cement lanes, asphaltic concrete (AC) shoulders	outside	outside	749	750	76 in./mi	76 in./mi	3.90
				inside	750		74 in./mi	74 in./mi	3.96
			inside	outside	750		73 in./mi	73 in./mi	3.99
				inside	750		75 in./mi	75 in./mi	3.93
			shoulder		751		145 in./mi	145 in./mi	2.42
3	Interstate 35, 2 southbound lanes and shoulders between MP 115 and 114	PC/AC lanes, AC shoulders	outside	outside	747	750	78 in./mi	78 in./mi	3.85/3.38*
				inside	746		83 in./mi	83 in./mi	3.73/3.25*
			inside	outside	748		81 in./mi	81 in./mi	3.78/3.30*
				inside	748		85 in./mi	85 in./mi	3.69/3.21*
			shoulder		747		110 in./mi	110 in./mi	2.79
4	Dayton Avenue, 2 lanes between Lincoln Way and North 13th	AC	north-bound	outside	593	750	96 in./mi	121 in./mi	2.65
					595		98 in./mi	124 in./mi	2.62
					595		101 in./mi	127 in./mi	2.59
				inside	602	750	96 in./mi	120 in./mi	2.67
					597		90 in./mi	113 in./mi	2.75
					597		95 in./mi	119 in./mi	2.68
			south-bound	outside	596	750	114 in./mi	143 in./mi	2.44
					597		111 in./mi	139 in./mi	2.47
					595		109 in./mi	137 in./mi	2.49
				inside	597	750	112 in./mi	141 in./mi	2.46
					595		110 in./mi	139 in./mi	2.47
					595		110 in./mi	139 in./mi	2.47
5	Dayton Avenue, 2 lanes between Lincoln Way and South 16th	PC	north-bound	outside	754	750	148 in./mi	147 in./mi	2.94
					755		143 in./mi	142 in./mi	2.98
					753		145 in./mi	144 in./mi	2.96
				inside	755	750	139 in./mi	138 in./mi	3.01
					752		137 in./mi	137 in./mi	3.02
					752		136 in./mi	136 in./mi	3.03
			south-bound	outside	752	750	137 in./mi	137 in./mi	3.02
					752		138 in./mi	138 in./mi	3.01
					753		138 in./mi	137 in./mi	3.02
				inside	751	750	124 in./mi	124 in./mi	3.14
					753		124 in./mi	124 in./mi	3.14
					750		122 in./mi	122 in./mi	3.16

Section	Description	Type	Lane	Wheel Track	Revolutions	Revs./Mile	Roughness Reading	BPR Road Roughness	LPV
6	Duff Avenue, 4 lanes between South 3rd and South 16th	AC	north-bound outside	outside	606	750	142 in./mi	176 in./mi	2.19
					607		140 in./mi	173 in./mi	2.21
					611		139 in./mi	171 in./mi	2.23
				inside	609	750	106 in./mi	131 in./mi	2.55
					609		107 in./mi	132 in./mi	2.54
					609		105 in./mi	129 in./mi	2.57
			north-bound inside	outside	610	750	104 in./mi	128 in./mi	2.58
					609		105 in./mi	129 in./mi	2.57
					610		107 in./mi	132 in./mi	2.54
				inside	610	750	103 in./mi	127 in./mi	2.59
					611		105 in./mi	129 in./mi	2.57
					611		99 in./mi	122 in./mi	2.64
			south-bound outside	outside	612	750	99 in./mi	121 in./mi	2.65
					610		94 in./mi	116 in./mi	2.71
					610		100 in./mi	123 in./mi	2.63
				inside	611	750	84 in./mi	103 in./mi	2.88
					612		84 in./mi	103 in./mi	2.88
					611		83 in./mi	102 in./mi	2.90
			south-bound inside	outside	611	750	90 in./mi	110 in./mi	2.79
					610		87 in./mi	107 in./mi	2.83
					611		86 in./mi	106 in./mi	2.84
				inside	608	750	83 in./mi	102 in./mi	2.90
					609		84 in./mi	103 in./mi	2.88
					607		84 in./mi	104 in./mi	2.87
7	Lincoln Way, 4 lanes between Duff Avenue and Grand Avenue	PC	east-bound outside	outside	392	750	99 in./mi	189 in./mi	2.66
					393		101 in./mi	193 in./mi	2.64
					392		98 in./mi	188 in./mi	2.67
				inside	394	750	87 in./mi	165 in./mi	2.81
					384		82 in./mi	160 in./mi	2.84
					382		83 in./mi	163 in./mi	2.82
			east-bound inside	outside	393	750	90 in./mi	172 in./mi	2.76
					390		88 in./mi	169 in./mi	2.78
					391		88 in./mi	169 in./mi	2.78
				inside	392	750	84 in./mi	161 in./mi	2.83
					389		82 in./mi	158 in./mi	2.85
					392		83 in./mi	159 in./mi	2.85

Table 6. Continued.

Section	Description	Type	Lane	Wheel Track	Revolutions	Revs./Mile	Roughness Reading	BPR Road Roughness	LPV
7 (cont'd)					381		103 in./mi	203 in./mi	2.59
			west-bound	outside	376	750	102 in./mi	203 in./mi	2.59
					376		103 in./mi	205 in./mi	2.58
			outside		377		93 in./mi	185 in./mi	2.68
				inside	381	750	92 in./mi	181 in./mi	2.71
					379		94 in./mi	186 in./mi	2.68
					386		96 in./mi	187 in./mi	2.67
			west-bound	outside	383	750	93 in./mi	182 in./mi	2.70
					392		98 in./mi	188 in./mi	2.67
			inside		386		84 in./mi	163 in./mi	2.82
				inside	386	750	84 in./mi	163 in./mi	2.82
					386		85 in./mi	165 in./mi	2.81

*This section is approximately half portland cement, half asphaltic concrete. Roughness readings were taken for the section as a whole. The values given are the LPV's of the lanes if they were entirely portland cement or entirely asphaltic concrete. Since it is not known how many inches of roughness accumulated before the pavement type changed, an exact LPV cannot be determined.



in the northbound direction was tested first in Section 1. Column 5 (Wheel Track) delineates which wheel track is being monitored in the test. The number of passes made over each section by the BPR equipment is shown in Column 6 (Revolutions) by the counter value obtained in the run. The standard of 750 revolutions per mile is shown in Column 7 (Revs/Mile). An Iowa DOT correlation table was used to translate the data into inches of roughness per mile shown in Column 8 (Roughness Reading) and into the standard BPR measure of roughness in Column 9 (BPR Road Roughness) and longitudinal profile value in Column 10 (LPV).

A single crack and patch survey was performed on all of the test sections on June 30 and July 1, 1986. The sections were surveyed in subsections approximately one-half mile long. Distress deductions were then calculated to be used in Eq. (1). Tables 7a, b, and c summarize the crack and patch survey. Table 7a describes the deductions made on the portland cement pavement sections, Table 7b provides similar data on the asphaltic concrete sections, and Table 7c describes the deductions for the two shoulder sections evaluated. Columns 1 and 2 of those tables identify the sections by number and location. The length of section evaluated is shown in Column 3. This is normally 0.5 miles but varied on some of the sections to gain a represenative sample of the conditions for this test only. The section driving surface or shoulder width are shown in Column 4 and the actual number of cracks counted in portland cement concrete or area of cracks in asphaltic concrete according to the prescribed procedure (see Appendix A) are included in Column 5. Column 6 indicates the area of the patches in square feet identified in the test area. The resulting measured values

Table 7a. Portland cement pavement Present Serviceability Index (PSI) distress deduction.

Section	Description	Length	Width	No. of Cracks	Patch Area	C	P	Distress Ded.	Supplemental D-Crack	Supplemental Ave. Rut Depth	Supplemental Ave. Fault
1	Interstate 35	0.5 mi	24 ft	2.0	0.0 ft^2	0.76	0.00	0.08	1	0.11 in.	0.07 in.
	2 northbound	0.5 mi	24 ft	10.0	20.0	3.78	0.32	0.18	0	0.07	0.07
	lanes between										
	MP 103 and 104										
	Total	1.0 mi	24 ft	12.0	20.0	2.27	0.16	0.13	1	0.09	0.07
2	Interstate 35	0.5 mi	24 ft	0.0	0.0	0.00	0.00	0.00	0	0.01	0.01
	2 northbound	0.5 mi	24 ft	0.5	0.0	0.19	0.00	0.04	0	0.04	0.01
	lanes and										
	shoulders										
	between MP 114										
	and 115										
	Total	1.0 mi	24 ft	0.5	0.0	0.09	0.00	0.02	0	0.03	0.01
3	Interstate 35	0.5 mi	24 ft								
	2 southbound	0.4 mi	24 ft	27.0	408.0	12.78	8.05	0.41	2	0.06	0.04
	lanes and										
	shoulders										
	between MP 115										
	and 114										
	Total										
4	Dayton Avenue	0.4 mi	22 ft								
	2 lanes between	0.4 mi	22 ft								
	Lincoln Way and										
	North 13th										
	Total	0.8 mi	22 ft								
5	Dayton Avenue	0.55 mi	24 ft	0.0	0.0	0.00	0.00	0.00	0	0.01	0.05
	2 lanes between	0.55 mi	24 ft	0.0	0.0	0.00	0.00	0.00	0	0.00	0.05
	Lincoln Way and										
	South 16th										
	Total	1.10 mi	24 ft	0.0	0.0	0.00	0.00	0.00	0	0.01	0.05
6	Duff Avenue	NB 0.65 mi	24 ft								
	4 lanes between	SB 0.65 mi	24 ft								
	South 3rd and										
	South 16th										
	Total	0.65 mi	48 ft								
7	Lincoln Way	EB 0.5 mi	24 ft	94.0	5,523.0	35.61	87.17	1.00	2	0.04	0.13
	4 lanes between	WB 0.5 mi	24 ft	95.5	6,602.0	36.17	104.20	1.07	2	0.02	0.15
	Duff Avenue and										
	Grand Avenue										
	Total	0.5 mi	48 ft	189.5	12,125.0	35.89	95.69	1.04	2	0.03	0.14

Table 7b. Asphaltic concrete pavement Present Serviceability Index (PSI) distress deduction.

Section	Description	Length	Width	Crack Area	Patch Area	Ave. Rut Depth	C	P	Distress Ded.	Supplemental: No. Transverse Cracks	Supplemental: No. Longitudinal Cracks	Ave. Fault
1	Interstate 35 2 northbound lanes between MP 103 and 104	0.5 mi	24 ft									
		0.5 mi	24 ft									
	Total	1.0 mi	24 ft									
2	Interstate 35 2 northbound lanes and shoulders between MP 114 and 115	0.5 mi	24 ft									
		0.5 mi	24 ft									
	Total	1.0 mi	24 ft									
3	Interstate 35 2 southbound lanes and shoulders between MP 115 and 114	0.5 mi	24 ft	0.0 ft^2	0.0 ft^2	0.02 in.	0.00	0.00	0.00	1	0	0.00 in.
		0.4 mi	24 ft									
	Total											
4	Dayton Avenue 2 lanes between Lincoln Way and North 13th	0.4 mi	22 ft	150.0	0.0	0.17	3.23	0.00	0.06	19	2	0.08
		0.4 mi	22 ft	400.0	0.0	0.13	8.61	0.00	0.05	17	2	0.07
	Total	0.8 mi	22 ft	550.0	0.0	0.15	5.92	0.00	0.06	18	2	0.07
5	Dayton Avenue 2 lanes between Lincoln Way and South 16th	0.55 mi	24 ft									
		0.55 mi	24 ft									
	Total	1.10 mi	24 ft									
6	Duff Avenue 4 lanes between South 3rd and South 16th	NB 0.65 mi	24 ft	2006.0	1068.0	0.15	24.35	12.97	0.09	26	6	0.04
		SB 0.65 mi	24 ft	300.0	364.0	0.14	3.64	4.42	0.06	26	6	0.02
	Total	0.65 mi	48 ft	2306.0	1432.0	0.15	14.00	8.69	0.08	52	12	0.03
7	Lincoln Way 4 lanes between Duff Avenue and Grand Avenue	EB 0.5 mi	24 ft									
		WB 0.5 mi	24 ft									
	Total	0.5 mi	48 ft									

Table 7c. Asphaltic concrete pavement Present Serviceability Index (PSI) distress deduction: shoulders only.

Section	Description	Length	Width	Crack Area	Patch Area	Ave. Rut Depth	C	P	Dist. Ded.	Supplemental: No. Trans. Cracks	Supplemental: No. Long. Cracks	Ave. Fault
2	Both outside and inside shoulders are surveyed as one section	0.5 mi	18 ft	0.00 ft^2	0.00 ft^2	0.02 in.	0.0	0.0	0.0	12	1	0.01 in.
		0.5 mi	18 ft	0.00 ft^2	0.00 ft^2	0.02 in.	0.0	0.0	0.0	2	0	0.00 in.
	Total	1.0 mi	18 ft	0.00 ft^2	0.00 ft^2	0.02 in.	0.0	0.0	0.0	7	1	0.01 in.
3	Both outside and inside shoulders are surveyed as one section	0.5 mi	16 ft	0.00 ft^2	14,630.00* ft^2	0.08 in.	0.0	346.4	0.2	24	0	0.05 in.
		0.4 mi	16 ft	0.00 ft^2	0.00 ft^2	0.00 in.	0.0	0.0	0.0	1	0	0.00 in.
	Total	0.9 mi	16 ft	0.00 ft^2	14,630.0 ft^2	0.04 in.	0.0	173.2	0.1	12	0	0.03 in.

*Approximately 1/3 of entire shoulder is covered by overlay (technically a patch).

for cracking (C) and patching (P) are shown in Columns 7-8. The distress deduction that results from using these values in the present serviceability equations are indicated in Column 9. The presence of D-cracking aggregates and the level of severity are indicated in Column 10. Columns 11-12 represent the mean field-measured values for asphaltic concrete rutting and portland cement joint faulting.

Using the LPV and distress deductions values in Eq. (1), we obtained the PSI values for all sections (see Table 8). The test locations are identified in Columns 1-2 of Table 8, the pavement surface type in Column 3, and the direction of travel and the lane of the survey in Column 4. The roughness as measured by the roadmeter in inches per mile in the outer wheel track (OWT), inner wheel track (IWT), and their average value are shown in columns 5-7. The longitudinal profile value in Column 8 represents the roadmeter value, and a deduction is made in Column 9 for the items identified as distress in Table 7 and used in the present serviceability equation in Appendix A. The resulting present serviceability index value is shown in Column 10.

PASCO Observations

PASCO used ROADRECON-70 to obtain crack and patch values, ROADRECON-75 to obtain rut depth, and ROADRECON-85B to obtain the roughness values in Sections 1, 2, 3, and 6, whereas ROADRECON-77 was used in Sections 4, 5, 6, and 7.

Table 8. Iowa present serviceability index values determined with longitudinal profile values and manual distress surveys.

Section	Terminus	Type	Dir.	Roughness OWT[1]	Roughness IWT[2]	Roughness Ave.[3]	LPV	PSI Ded.[4]	PSI
1	I-35 MP[5] 103-104	PC[6]	NB[7] (OSL)	77	77	77	3.87	0.13	3.74
			NB (ISL)	76	70	73	3.98	0.13	3.85
	(Car Counter Cable Across Road)								
2	I-35 MP 114-115	PC	NB (OSL)	76	74	75	3.93	0.02	3.91
			NB (ISL)	75	73	74	3.96	0.02	3.94
	Shoulders	AC[8]	NB			145	2.42	--	--
3	I-35 MP 114-115	PC	SB[9] (OSL)	78	83	81	3.78	0.41	3.37
			SB (ISL)	85	81	83	3.74	0.41	3.33
	Shoulders	AC	SB			110	2.79	0.00	2.79
4	Dayton Rd. Between	AC	NB	144	137	141	2.46	0.06	2.40
	Lincoln Way and 13th		SB	137	123	130	2.56	0.06	2.50
5	Dayton Rd. Between	PC	NB	125	117	121	3.18	0.00	3.18
	Lincoln Way and US 30		SB	140	140	140	2.99	0.00	2.99
6	Duff S. 4th to S. 16th	AC	NB (OSL)[10]	173	131	152	2.38	0.09	2.29
	US 69		NB (ISL)[11]	129	126	128	2.56	0.09	2.47
			SB (OSL)	120	103	112	2.76	0.06	2.70
			SB (ISL)	108	103	106	2.85	0.06	2.79
7	Lincoln Way Duff to Grand	PC	EB[12] (OSL)	190	163	177	2.73	1.00	1.73
	US 69		EB (ISL)	170	159	165	2.81	1.00	1.81
			WB[13] (OSL)	204	184	194	2.63	1.07	1.56
			WB (ISL)	186	164	175	2.74	1.07	1.67

[1]Outer wheel track

[2]Inner wheel track

[3]Average

[4]Deduction

[5]MP = Mile post

[6]PC = Portland cement

[7]NB = Northbound

[8]AC = Asphalt

[9]SB = Southbound

[10]OSL = Outer side lane

[11]ISL = Inner side lane

[12]EB = Eastbound

[13]WB = Westbound

PASCO Data Collection Procedures

Setting up ROADRECON-70 takes about 20 minutes by two persons. After the necessary cables are connected, the slit camera is mounted and the camera boom is extended, adjusted, and secured. Since speeds below 1.25 mph (2 km/h) causes overexposure of the film, a running start is necessary at the beginning of the section as well as at each stop. A strip on the ground of about 0.3 to 0.4 in. (8 to 9 cm) in length is blanked out during stops. These films are then sent for developing, printing, and interpretation. Figure 12 shows typical strip photography by the slit camera.

It takes two persons about 30 minutes to set up ROADRECON-75 (the pulse camera). The slit camera is replaced with the pulse camera, the hairline projector is mounted, and the camera boom is extended, adjusted, and secured. The first pulse photo is taken manually to include pavement markings at the beginnings of the sections. The rest of the photos are taken automatically at given intervals of pavement travel. Two or three photographs are taken at the end of each section. The film is then sent for developing, printing, and plotting of the cross profile. Figure 13 shows a typical pulse camera photograph and Fig. 14 shows a typical cross profile of the pavement from which rut measurements are made.

Assembly time for the ROADRECON-77 is minimal since the system is mounted on the survey vehicle. A check of the connections and the paper feeds, which takes about five minutes, is done before the operation. The system is started well before the operation, and a mark on

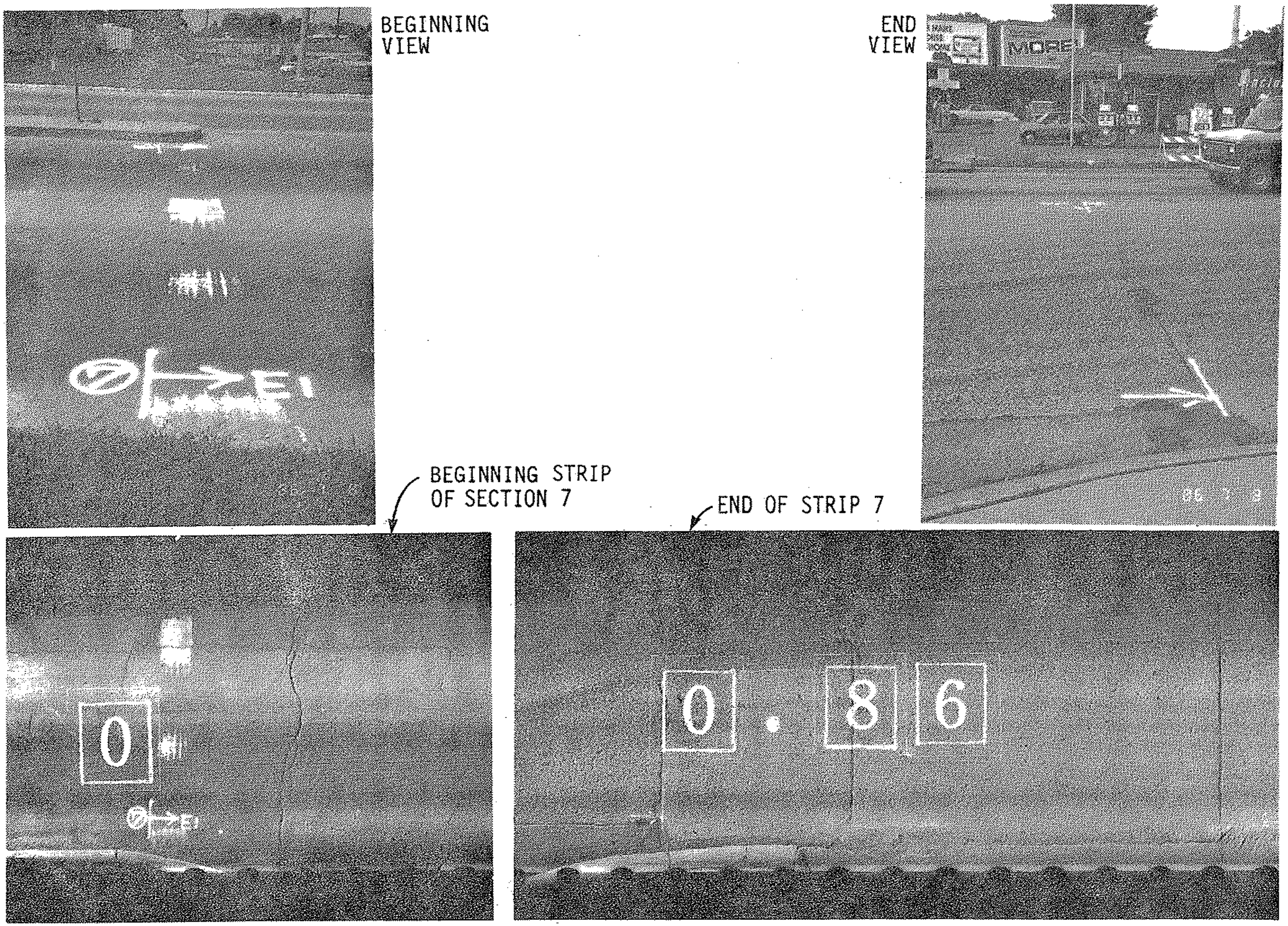


Fig. 12. Continuous strip photograph.

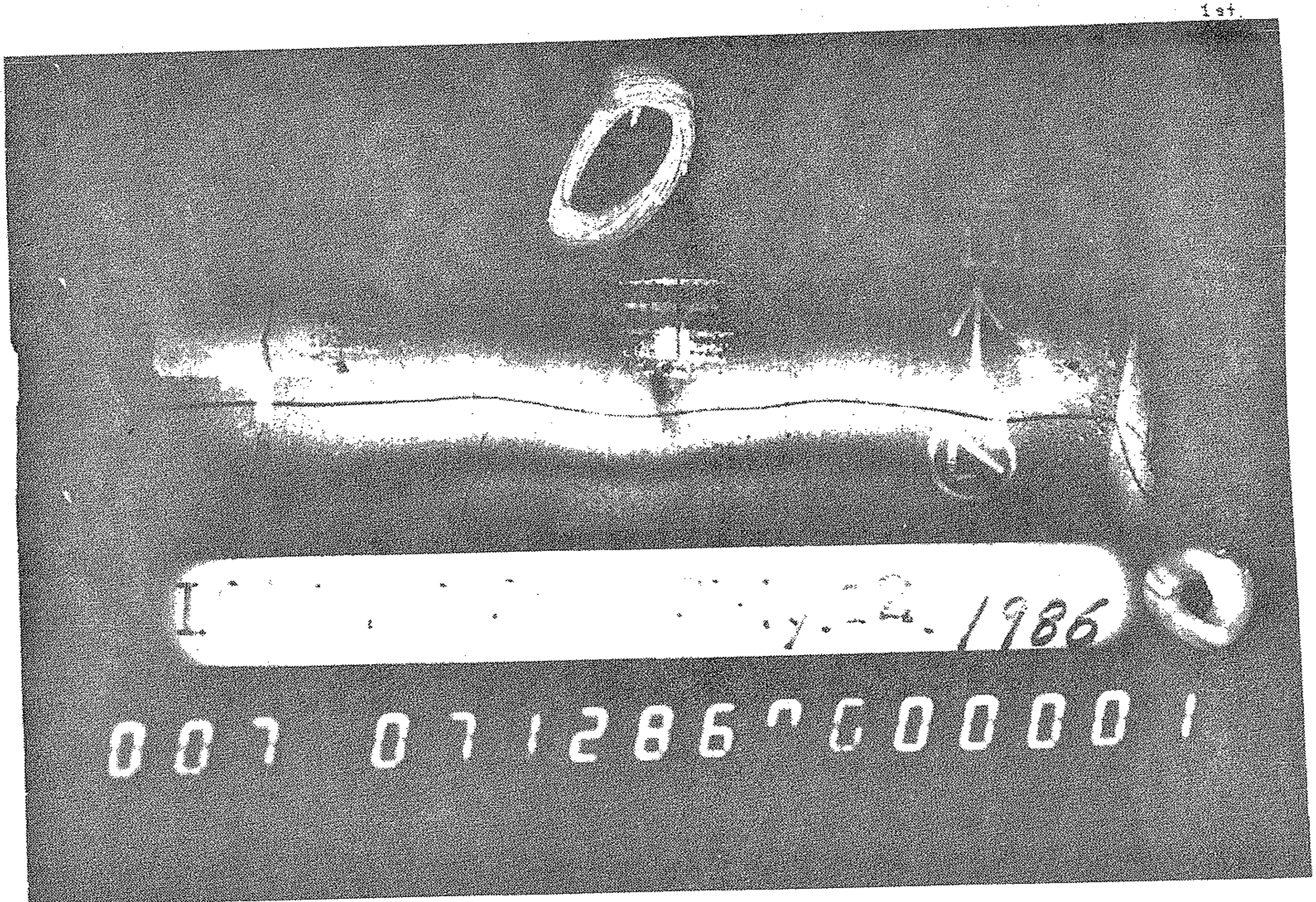


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Fig. 13. Pulse photograph.

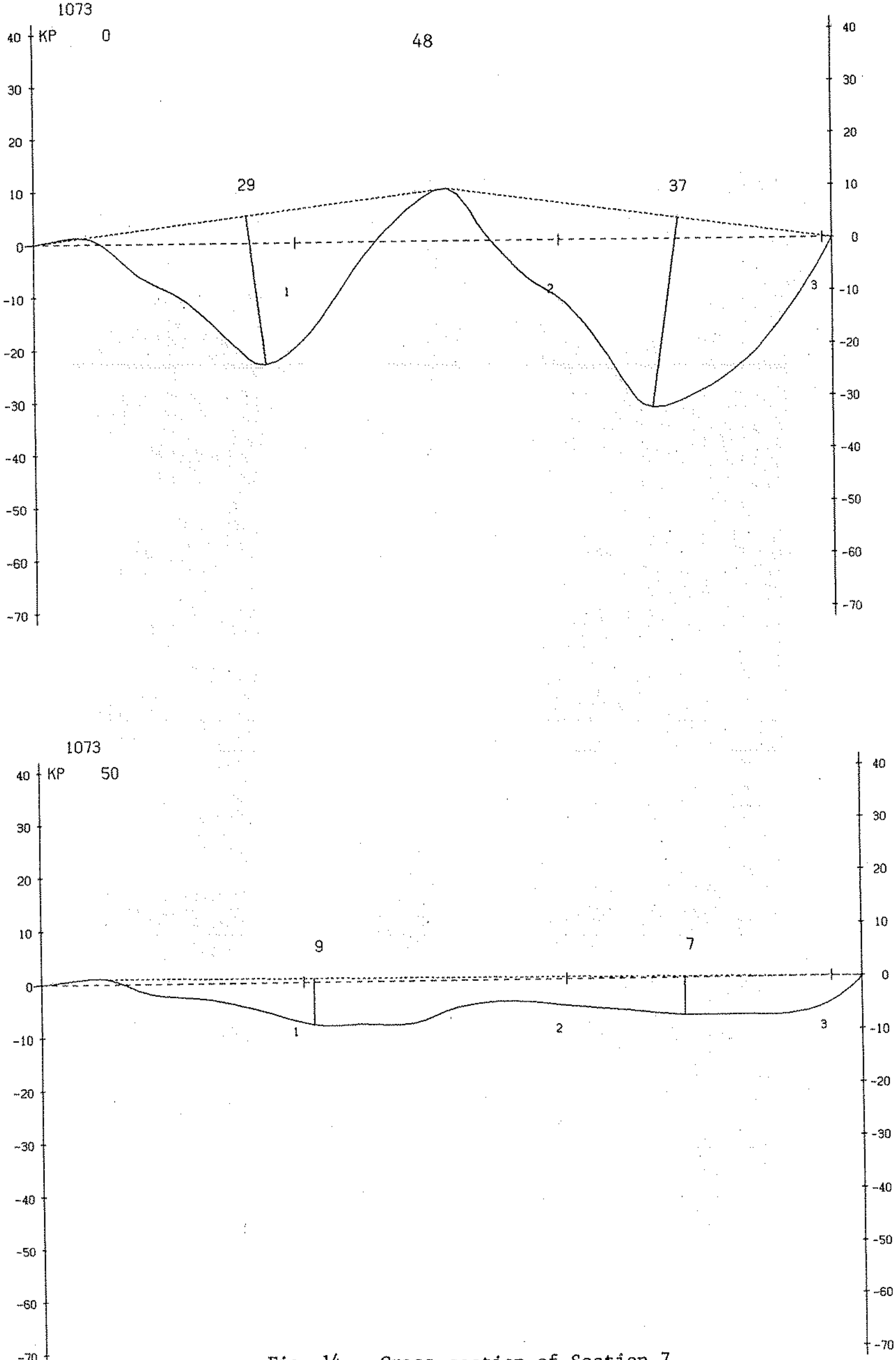

Fig. 14. Cross section of Section 7.

the paper chart is made manually at the beginning and end of the section. The cassette and the paper chart are sent for computations of the roughness. Figure 15 shows the paper chart of a typical run. The strip chart is broken into four separate tracing areas longitudinally. The upper trace is used to identify the distance traveled along the top of the trace area with 0.08 in. (2 cm) along the paper being equal to 8.9 ft (2 m) of travel. The second line of data within the same trace is the longitudinal profile of the section surveyed. The vertical scale on the graph is 2.0 in. of roughness per 0.4 in. (10 mm). The second trace area contains a plot of the speed of the survey vehicle. Its scale is 6.25 mph (10 km/h) for each 0.4 in. (10 mm) on the vertical scale. The third trace contains vertical tick marks near the center that represent the TCR count with each one equal to 0.4 in. (1 cm) of additional roughness. The additional information shown in this section was not used in this test and pertains only to the manufacturer's needs. The final trace area is used to make notes relative to particular problems noted in the survey such as the location of intersections or other special features along the route.

For ROADRECON-85B the mounting of the lasers takes about 10 to 15 min. Checking of proper connections and paper feeds takes another 5 min. Model 85 utilizes premounted laser units that require no setup time, but this model was unavailable for the test evaluation. The system is started well before the operation, and marks are made on the paper chart manually at the beginning and end of each section. The charts and the cassette tape are sent for computations of the roughness. Figure 16 shows the paper chart of a portion of a section. This chart is laid

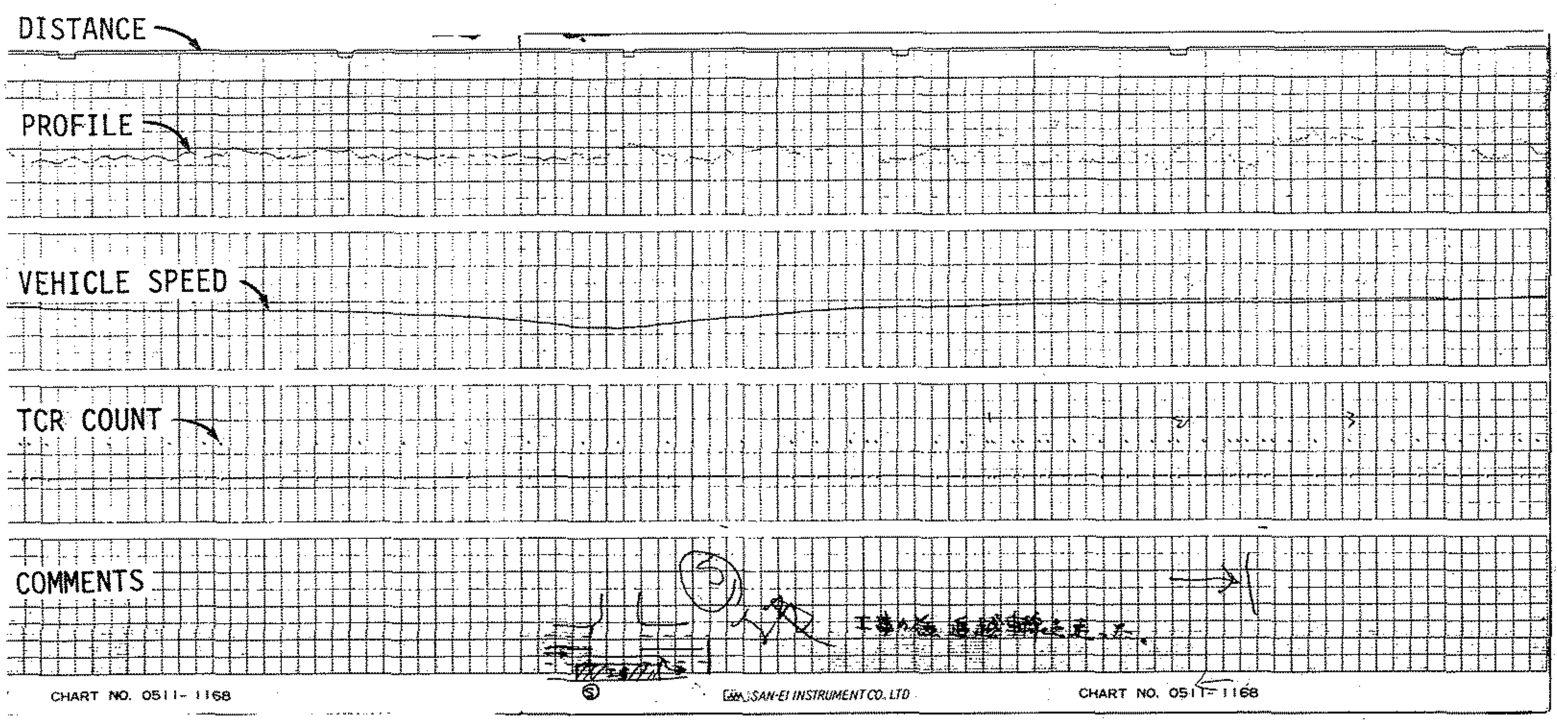

Fig. 15. Paper chart (longitudinal profile) by tracking wheel.

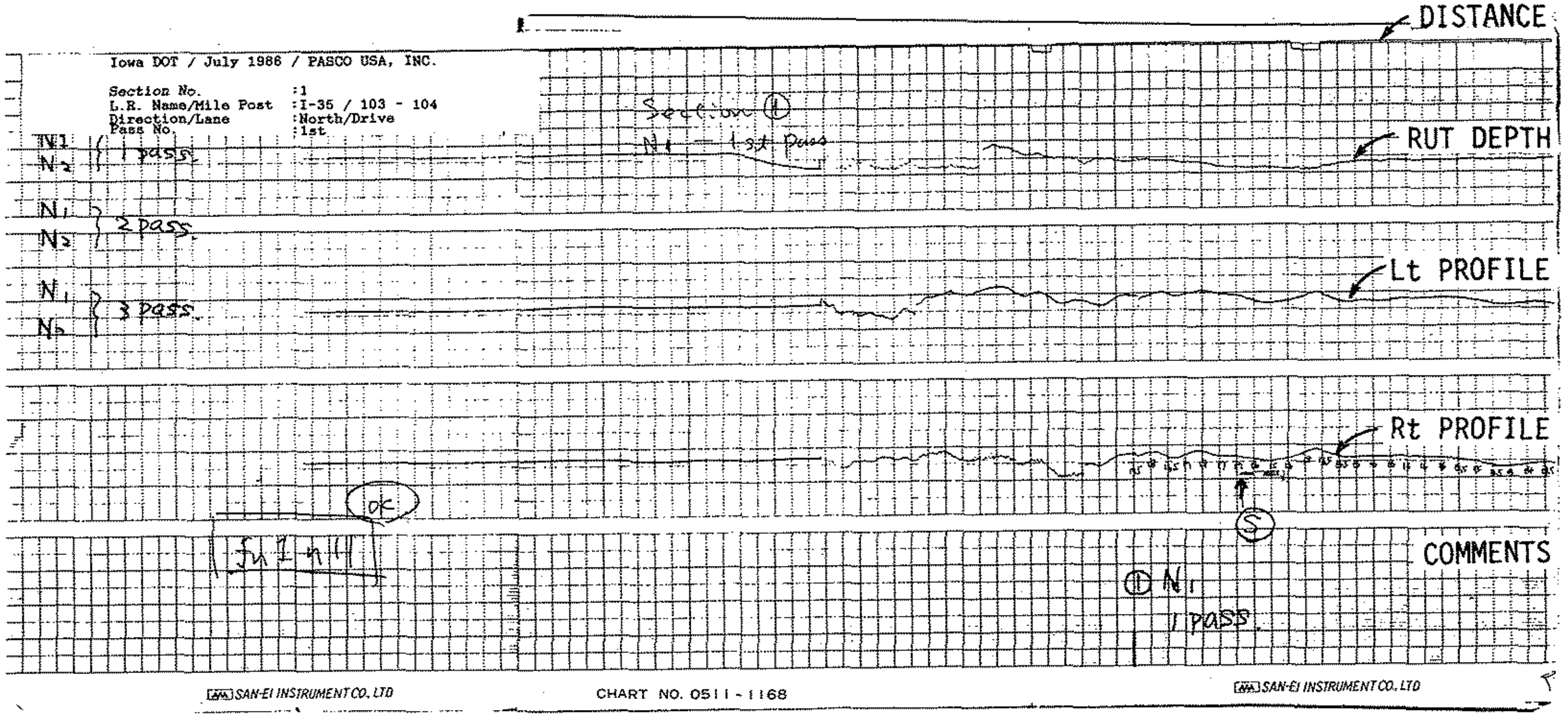

Fig. 16. Longitudinal profile by laser.

out in a manner similar to that used in the ROADRECON-77 example. Distance is measured in the same manner along the top of the chart. The second line of data on the top trace is the rut depth in this instance and utilizes a scale of 2.0 in. for each 0.4 in. (10 mm) of graph vertically. The second trace area uses the same vertical scale to describe the profile at the left edge of the test vehicle, and a similar condition exists in the third trace to identify the right edge of the test vehicle laser trace of roughness. The fourth trace area is again used for notes on the route features.

PASCO Data

On the first night, July 8, 1986, distress surveys of Sections 4, 5, 6, and 7 were made with the slit camera on each lane. Eleven full stops at traffic lights were made; however, because of multiple runs, all gaps produced by stops were photologged. In order to list the suitability of using the "wetting" technique in distress surveys to detect hairline cracks in new pavement, the northbound lanes of Section 6 were watered with about 0.044 gal/sq yd (200 cc/m^2) of water, and one pass of photographs was taken an hour and a half after wetting. Another pass of photographs was taken one hour after the first pass. The survey of Sections of 4 and 5 was done between the wet runs on Section 6.

On the second night, distress surveys and roughness surveys were done on Section 1 by ROADRECON-85B (laser). Because of fog, the vehicle was stopped once to clean the lens system. Only one pass on Sections 2, 3, and shoulders was done on this night because of foggy conditions.

On the third day, roughness surveys using ROADRECON-77 on Sections 4, 5, 6, and 7 were done during the daytime. The cruising speed of the vehicle was about 40 km/hr.

On the third night, distress surveys (with the slit camera) and roughness surveys (with the laser) were completed for Sections 2 and 3. In the same night the slit camera was replaced with the pulse camera, and rut surveys for 1, 2, and 3 were done. Because of rain only two passes on the driving lane (DL) and one pass on the passing lane (PL) of Section 1 were completed.

On the fourth night, the rut depth surveys were completed for Section 1. Rut depth surveys were also taken then on Sections 4, 5, 6, and 7.

All the data collected were sent to PASCO's main office in Japan for processing. The processed data were received during the latter part of August 1986. Table 9 shows a typical evaluation sheet containing the cracking, patching, rut depth, and MCI data for subsections in Section 7. The table is designed to meet the needs of the equipment manufacturer's home country needs and was adapted to the Iowa project. Information at the top of the table is used to identify the pass number on the section, the test section number and the lane. The test section has been broken down into subsections of basically 0.1 mile segments for the data collection. The succeeding columns that are identified in English are a record of the amount of cracking, patching, maximum rut depth, mean rut depth and the standard deviation (SD) value obtained

Table 9. Typical PASCO evaluation sheet.

路 面 性 状 デ ー タ 一 覧 表

U. S. A.

PASS # → 1073 ← LANE #

SECTION #

CRACK — PATCH — TOTAL — max RD — MEAN RD — SD

SUB-SECTION

距離程 (km) 自	距離程 (km) 至	ブレーキ	構造物 1	構造物 2	区間延長 (m)	測定値 調査年度	測定値 路面種別	測定値 ひびわれ率（度）(%, cm/m²) クラック	測定値 ひびわれ率 パッチング	測定値 ひびわれ率 計	測定値 わだち掘れ量 (mm) 最大値	測定値 わだち掘れ量 平均値	測定値 縦断凹凸量 σ (mm)	測定値 MCI 最小	測定値 MCI式	予測値（昭和 年 月） 路面種別	予測値 ひびわれ率（度）(%, cm/m²)	予測値 わだち掘れ量 (mm) 最大値	予測値 わだち掘れ量 平均値	予測値 縦断凹凸量 σ (mm)	予測値 MCI 最小	予測値 MCI式	舗設年度	最新補修 年度	最新補修 工法	経年数	地域区分(1)	地域区分(2)	道路区分	CBR (%)	TA (cm)	摘要
0.0	0.065				65	S61	AS	27.2	1.2	28.4	37	31	9.36	2.0	1																	
0.065	0.085				20	S61	CO	10.7	6.4	32.1	9	9	9.36	2.3	3																	
0.085	0.100				15	S61	AS	10.7	0.0	10.7	9	9	9.36	4.9	1																	
0.100	0.110				10	S61	AS	44.9	10.7	55.6	3	3	5.25	2.6	3																	
0.110	0.200				90	S61	CO	10.5	1.1	14.2	3	3	5.25	4.6	3																	
0.200	0.300				100	S61	CO	10.3	0.6	12.2	3	3	5.06	5.0	3																	
0.300	0.400				100	S61	CO	9.6	1.4	14.4	12	8	4.39	4.6	1																	
0.400	0.500				100	S61	CO	15.6	1.0	18.9	3	3	4.30	4.0	3																	
0.500	0.600				100	S61	CO	16.1	3.1	26.6	3	3	6.11	3.0	3																	
0.600	0.700				100	S61	CO	10.4	1.6	15.9	7	5	3.63	4.4	3																	
0.700	0.800				100	S61	CO	7.3	2.4	15.2	4	4	6.02	4.5	3																	
0.800	0.860				60	S61	CO	22.4	5.1	39.5	7	7	6.88	1.6	3																	

in the PASCO methods of collection. The table also indicates in the following columns the use of the values to obtain an MCI value used in the same manner as the Iowa PSI to establish relative condition ratings between highway sections. The results of the survey of each of the seven sections of highway are shown in Table 10. The values shown in columns 3-22 represent the MCI values obtained by PASCO on the noted lane or shoulder. The MCI scale is on the basis of 1-10 in the same manner as the PSI scale of 1-5 with the highest number being best and the lowest number being worst.

Comparison of Iowa DOT and PASCO Results

So that the two systems could be compared, it was decided to convert the PASCO results to the scale and units of the Iowa DOT. The Iowa DOT computes the roughness (BPR method) in inches per mile. The PASCO computes SD (mm) or TCR (mm) for each subsection. The SD or TCR of each subsection is converted to inches, then summed and divided by the length of the section in miles to give the roughness in inches per mile.

Tables 11a and 11b show the comparison. Using information obtained from the BPR roadmeter and the methodology employed by the PASCO equipment, we compared the SD and TCR values from successive runs. Using the ROADRECON-77 at 25 mph and ROADRECON-85 at 40 mph, we compared the results in terms of inches per mile in Table 11a and 11b. Note that although the TCR values from the ROADRECON-77 are higher than that correlation to the BPR values in the first line, they do provide consistent

Table 10. Evaluation of automated data collection equipment for determining pavement condition (data table of PASCO's standard pavement evaluation method).

Section No.	1		2			3			4		5		6				7			
Legislative Route Name	I-35		I-35			I-35			Dayton Ave.		S. Dayton Ave.		S. Duff Ave.				Lincoln Way			
Section Length (mile post)	1 mi (103-104)		1 mi (114-115)			1 mi (115-114)			0.8 mi		1.01 mi		0.839 mi				0.538 mi			
Pavement Type	Concrete		Concrete			Asphalt			Asphalt		Concrete		Concrete/Asphalt				Concrete			
Direction	North		North			South			North	South	North	South	North		South		West		East	
Lane ID	DR[1]	PA[2]	SH[3]	DR	PA	SH	DR	PA	DR	DR	DR	DR	DR	PA	DR	PA	DR	PA	DR	PA
1. MCI value based on CR/RD/SD (ROADRECON 70; 75; 77)																				
1st pass	6.4	7.3	6.9	8.3	8.1	8.5	8.5	8.7	5.2	4.9	8.1	7.3	3.3	3.6	3.1	3.7	3.3	3.4	4.0	4.9
2nd pass	6.5	7.3	6.9	8.3	8.1	8.5	8.5	8.7	5.2	4.9	8.1	7.8	3.1	3.7	3.0	3.8	3.3	3.4	4.0	4.9
3rd pass	6.5	7.3	6.9	8.2	8.1	8.6	8.6	8.7	5.1	4.9	8.1	7.7	3.2	3.7	3.1	3.8	3.3	3.4	4.0	4.8
2. CR (%) based on ROADRECON 70																				
1st pass	4.6	2.4	6.7	0.0	0.3	0.1	0.0	0.1	12.6	16.1	0.1	0.1	36.6	32.4	42.1	30.2	24.5	23.2	19.0	12.7
2nd pass	4.6	2.4	6.7	0.0	0.3	0.1	0.0	0.1	12.6	16.0	0.1	0.1	36.9	32.4	42.1	30.0	24.6	23.1	19.1	12.5
3rd pass	4.6	2.4	6.7	0.0	0.3	0.1	0.0	0.1	13.0	16.0	0.1	0.1	36.6	32.4	42.0	30.0	24.9	23.2	19.1	12.6
3. RD (mm) based on ROADRECON 75																				
1st pass	7.4	3.6	3.9	3.2	4.9	3.3	4.1	3.0	6.0	6.1	5.6	6.5	11.8	8.9	10.2	9.8	5.7	4.2	4.5	3.9
2nd pass	6.8	3.6	4.4	5.1	5.1	3.4	4.1	3.2	5.6	6.4	5.4	6.9	14.0	9.0	12.0	8.5	5.3	4.6	5.7	4.0
3rd pass	6.8	3.4	4.1	5.4	5.0	3.3	4.1	3.0	5.8	6.2	5.7	7.0	13.3	9.1	11.0	8.7	4.4	3.8	6.0	5.9
4. SD (mm) based on ROADRECON 77 or 85-B																				
1st pass	6.0	5.7	---	5.8	5.5	---	5.2	4.6	2.3	2.7	2.5	2.4	4.5	2.9	2.5	2.4	5.8	5.0	5.2	4.1
2nd pass	6.2	5.5	---	4.5	4.7	---	4.3	4.3	2.4	---	2.6	---	4.6	3.1	2.8	2.4	5.6	4.7	---	3.8
3rd pass	6.5	6.1	---	4.5	4.3	---	4.0	3.8	2.4	2.8	2.6	2.4	4.7	3.2	3.0	2.3	5.8	4.9	5.4	3.8

[1]DR = Driving lane

[2]PA = Passing lane

[3]SH = Shoulder

Table 11a. Evaluation of automated data collection equipment for determining pavement condition (data table of BPR roughometer and ROADRECON-77) at 25 mph.

Section No.	4		5		6				7			
Legislative Route Name	Dayton Ave.		S. Dayton Ave.		S. Duff Ave.				Lincoln Way			
Section Length (mile post)	0.8 mi		1.01 mi		0.839 mi				0.530 mi			
Pavement Type	Asphalt		Concrete		Concrete/Asphalt				Concrete			
Direction	North	South	North	South	North		South		West		East	
Lane ID	DR[1]	DR	DR	DR	DR	PA[2]	DR	PA	DR	PA	DR	PA
1. TCR[3] (in/mile) based on BPR												
1st pass	144	137	127	140	173	129	120	108	204	186	190	170
2. SD[4] (mm) based on ROADRECON 77												
1st pass	2.3	2.7	2.5	2.4	4.5	2.9	2.5	2.4	5.8	5.0	5.2	4.1
2nd pass	2.4	---	2.6	---	4.6	3.1	2.8	2.4	5.6	4.7	---	3.8
3rd pass	2.4	2.8	2.6	2.4	4.7	3.2	3.0	2.3	5.8	4.9	5.4	3.8
3. TCR (in/mile) based on ROADRECON 77												
1st pass	161	190	166	163	284	196	170	166	399	388	400	326
2nd pass	168	---	172	---	287	207	181	169	380	366	---	311
3rd pass	163	192	174	161	292	207	198	159	391	381	405	303
4. SD (mm) based on ROADRECON 85B												
1st pass	---	---	---	---	8.5	---	8.1	---	---	---	---	---
2nd pass	---	---	---	---	9.0	---	7.5	---	---	---	---	---
3rd pass	---	---	---	---	8.4	---	7.3	---	---	---	---	---
5. TCR (in/mile) based on ROADRECON 85B												
1st pass	---	---	---	---	301	---	256	---	---	---	---	---
2nd pass	---	---	---	---	287	---	193	---	---	---	---	---
3rd pass	---	---	---	---	210	---	170	---	---	---	---	---

[1]DR = Driving lane

[2]PA = Passing lane

[3]TCR = Total cumulative roughness

[4]SD = Standard deviation (longitudinal roughness)

Table 11b. Evaluation of automated data collection equipment for determining pavement condition (data table of BPR and ROADRECON-85B) at 40 mph.

Section no.	1		2		3		6*	
Legislative route name	I-35		I-35		I-35		S. Duff Ave.	
Section length (mile post)	1 mi (103 - 104)		1 mi (114 - 115)		1 mi (115 - 114)		0.839 mi	
Pavement type	Concrete		Concrete		Asphalt		Co/As	
Direction	North		North		South		North	South
Lane ID	DR	PA	DR	PA	DR	PA	DR	DR
1. TCR(in./mile) based on BPR								
1st pass	77	76	76	75	78	85	173	120
2. SD(mm) based on ROADRECON-85B								
1st pass	6.0	5.7	5.8	5.5	5.2	4.6	8.5	8.1
2nd pass	6.2	5.5	4.5	4.7	4.3	4.3	9.0	7.5
3rd pass	6.5	6.1	4.5	5.3	4.0	3.8	8.4	7.3
3. TCR(in./mile) based on ROADRECON-85B								
1st pass	162	140	131	130	115	105	301	256
2nd pass	165	142	99	118	92	93	287	193
3rd pass	164	147	118	122	89	82	210	170

*At 25 mph.

values between runs. The same consistency can be seen in the SD values for this unit. A similar set of numbers was obtained for the ROADRECON-85, but the spread is greater between passes. Examples of the relationship between the ROADRECON units and the BPR are shown graphically in Appendix C. The correlation between Iowa DOT versus PASCO (77) was about 0.93; for Iowa DOT versus PASCO (85B) it was about 0.84. The sample is very limited and would indicate additional testing is necessary to verify the total accuracy and repeatability of the ROADRECON-85 unit. The limited sample does indicate the improved results at 40 mph versus 25 mph testing. The correlation for the laser is low because of insufficient data and perhaps also because of multiple reflection of the laser beam.

In the Iowa DOT method, rut depths are given as an average (in inches) for each section. The PASCO results are in means (in millimeters) for each subsection. The PASCO results are converted to an average for each section by taking the mean of subsection means. Table 12 gives the rut depth values for PASCO and Iowa DOT methods for each section. The correlation coefficient is about 0.61 (see Fig. C.5). The low correlation proabaly results from the PASCO system using the shoulder of the pavement as a reference to measure the rut depth whereas Iowa DOT uses a four-foot rod across the rut to measure the depth. Furthermore, the rut depths measured by PASCO are consistently larger than those measured by Iowa DOT. The ROADRECON unit measures vertical changes in height across the lane by using the edges of the lane as the reference points. In this way both rutting and shoving of the material can be identified relative to the pavement edges and the shoulder.

Table 12. Average rut depth (inches).

Section	PASCO	Iowa DOT
1	0.22	0.09
2	0.20	0.025
2Sh[1]	0.15	0.02
3P[2]	0.31	0.06
3A[3]	0.14	0.02
3PSh	0.70	0.11
3ASh	0.13	0.0
4	0.24	0.105
5	0.24	0.007
6N[4]	0.33	0.15
6S[5]	0.35	0.14
7W[6]	0.20	0.02
7E[7]	0.18	0.04

Iowa DOT vs PASCO Results:

Number of data = 13
Intercept = +0.0046
t = 2.57
Slope = +0.2144
Correlation coefficient r = 0.6137
Goodness of fit r^2 = 0.0367

[1]Sh = Shoulder

[2]P = Portland cement

[3]A = Asphalt

[4]N = North

[5]S = South

[6]E = East

[7]W = West

This identifies changes in elevation that are overlooked with the four-foot straightedge method.

The cracks in asphalt are given as square feet of cracks per 1000 sq ft in the Iowa DOT method, whereas in the PASCO method it is given as percentage of pavement in each subsection. In order to make the PASCO values correspond with Iowa DOT values the following methods were adopted:

1. The areas of cracks were determined from the percentage values.
2. The areas of cracks and subsections were summed to give the total areas of cracks in the section and total area of the section.
3. The total cracked area is divided by the total pavement area in thousands of square feet surveyed to obtain the area of cracks in square feet per 1,000 sq ft of pavement area.

For example: Assume that a 1,000-ft by 24-ft pavement is subdivided into 10 subsections each 100 ft in length. The cracked area in percent in each subsection is as follows: 10%, 5%, 5%, 10%, 15%, 10%, 10%, 15%, 10%, 5%. The corresponding areas in square feet are 240, 120, 120, 240, 360, 240, 240, 360, 240, and 120 for a total of 2,280 sq ft. The total pavement area is 1,000 by 24 = 24,000 sq ft. The cracked area of 2,280 sq ft is divided by 24,000 sq ft of pavement area and then multiplied by 1,000 to obtain the amount of cracked area per 1,000 sq ft of pavement, which is 95 in this example.

In the case of concrete pavement, Iowa DOT gives the cracks in feet per 1000 sq ft. The PASCO methods give the centimeter of cracks per square meter of pavement in each section. The PASCO values were converted to feet of cracks per 1000 sq ft as follows:

1. The area of each subsection was computed.

2. The centimeters of cracks per square meter in each section were multiplied by the area of subsection to give the centimeters of cracks in that subsection. The centimeters of cracks in each subsection were then totalled to give the total length of cracks in that section.

3. The total length in centimeters of cracks was converted to feet.

4. The total area of the section in square meters was converted to square feet and then divided by 1000 to give the area of pavement in square feet.

5. The total length in feet of cracks was then divided by 1000 square feet of pavement to give feet of cracks per 1000 square feet.

Table 13 shows the comparison of cracks by the two methods. After eliminating a possible error in Section 4, the correlation was found to be 0.32 (see Fig. C.6). The low correlation is probably due to the fact that the PASCO method included hairline cracks, whereas the Iowa DOT method used only large cracks visible to an observer. Again, the values obtained by PASCO are consistently larger than those obtained by Iowa DOT.

In the case of patches the Iowa DOT gives the values in square feet of patches per 1000 square feet, whereas the PASCO method gives in percentage of total pavement area in each subsection. The PASCO values are converted to square feet of patches per 1000 square feet, just as they are in determining the area of cracks in asphalt pavement. Table 14 shows the patch comparison. After an error in a Section 3 shoulder was eliminated, the correlation was found to be 0.66 (see Fig. C.7).

Table 13. Cracks (square feet) per 1000 square feet pavement.

Section	PASCO	Iowa DOT
1	9.775	2.275
2	0.25	0.09
2Sh[1]	13.5	0
3P[2]	264.9	12.78
3A[3]	0.03	0
3PSh	0.25	0
3ASh	1.36	0
[4	143.4	275]
5	0.25	0
6NA[4]	329.92	24.35
6NP	3.32	24.35
6SA[5]	290.92	3.64
6SP	8.21	3.64
7W[6]	83.69	36.17
7E[7]	68.57	35.61

Iowa DOT vs PASCO Results:

Number of data = 15
Intercept = +18.1579
Slope = +0.1195
Correlation coefficient
r = 0.2036
Goodness of fit r^2 = 0.0414

With the bracketed pair omitted:

Number of data = 14
Intercept = +7.3827
Slope = +0.0368
Correlation coefficient
r = 0.3235
Goodness of fit r^2 = 0.1047
t = 1.18

[1]Sh = Shoulder

[2]P = Portland cement

[3]A = Asphalt

[4]N = North

[5]S = South

[6]W = West

[7]E = East

Table 14. Area of patches (square feet) per 1000 square feet pavement.

Section	PASCO	Iowa DOT
1	14	0.16
2	5	0
2Sh[1]	53.75	0
3P[2]	1	8.05
3A[3]	7	0
[3PSh	11.25	692.7]
3ASh	0	0
4	1.7	0
5	1	0
6NA[4]	14.74	12.97
6NP	0.55	12.97
6SA[5]	5.48	4.42
6SP	3.50	4.42
7W[6]	63.65	104.20
7E[7]	27.31	87.17

Iowa DOT vs PASCO Results:

Number of data = 15
Intercept = +51.249
Slope = +0.754
Correlation coefficient r = 0.083
Goodness of fit r^2 = 0.007

With the bracketed pair omitted:

Number of data = 14
Intercept = +1.146
Slope = +1.099
Correlation coefficient r = 0.660
Goodness of fit r^2 = 0.436
t = 3.04

[1]Sh = Shoulder

[2]P = Portland cement

[3]A = Asphalt

[4]N = North

[5]S = South

[6]W = West

[7]E = East

As discussed earlier, the Iowa DOT gives the total evaluation in PSI (on a scale of 0 to 5) whereas the PASCO gives it in MCI (on a scale of 0 to 10). Table 15 shows the PSI versus MCI values. The correlation between the two is about 0.77 (see Fig. C.8).

Comparison of Iowa DOT Visual Crack and Patch Survey Versus PASCO Survey Method

In an effort to illustrate the increased accuracy obtained in crack and patch surveys by film, a separate test was conducted on December 19, 1986. A trained crack and patch technician from the Iowa DOT reviewed one lane-mile of Section 7 on film. Adjusting his recorded measures to four lane-miles for the test section and comparing them to the visual tests made in the field at the time of the PASCO evaluation, he obtained the following results:

Section 7	Field Survey	Film Survey
Number of full cracks	95.5	126
Patched area in sq ft	6,602.0	7,860

The differences reflect the increased detail that can be observed on film at a constant vertical angle and over a complete project length versus one-half mile segment. The significance of the length viewed can only be measured over time, but it gives a full picture of the site for detailed rehabilitation planning. This planning ability could result in

Table 15. PSI and MCI linear regression.

Section	PSI	MCI
1	3.74	6.4
	3.85	7.3
2	3.94	8.3
	3.91	8.1
3	3.37	8.7
	3.33	8.5
	2.79	8.5
4	2.4	4.9
	2.5	5.2
5	2.99	7.8
	3.18	8.1
6	2.47	3.6
	2.29	3.3
	2.70	3.1
	2.79	3.7
7	1.56	3.3
	1.67	3.4
	1.73	4.0
	1.81	4.9

Results:

MCI vs PSI

Intercept = -0.139

Slope = +2.145

Goodness of fit r^2 = 0.579

PSI vs MCI

Intercept = +1.212

Slope = +0.270

Goodness of fit r^2 = 0.579

n = 19 r = 0.769

Approximate work time: 1 hr.

$$t = \frac{R^2(n - 2)}{1 - R^2}$$

$$= 48$$

a savings to the state by identifying the size and location of future spot overlays or full depth patches.

The observer was able to view one lane-mile in 30 minutes with no prior training. Three to five lane-miles per hour average viewing ability should be attainable after the operator receives one- to two-days of training in addition to field experience.

The trained observer will provide much better data for statistical comparison than can be obtained in this small test sample. The increased objectivity will provide the Department of Transportation with a more objective rating of pavement conditions across the state and over time than is possible with seven individual crews of persons operating independently. It will allow the crews to be used for other important work in the Department and will allow for continual updating of the system throughout the year rather than during the winter only.

This system represents the next step in the progress toward full automation of the condition evaluation process. It will prepare the Department of Transportation for the use of video film data collection, laser disk retrieval, and expert system analysis of the data as those technologies are made available, without any major changes in the data collection and analysis procedures employed by PASCO.

5. EVALUATION OF RESULTS

General

The MCI values obtained for the first pass and second pass by the PASCO method agree with each other at a 99% confidence level or better (see Fig. C.9).

Correlation of Data

Patching and cracking, rut depth, and roughness obtained for the first pass and second pass by ROADRECON-70, -75, and -77 of the PASCO method agree with each other at a 99% confidence level (Figs. C.10-C.12). The roughnesses obtained by a first and second pass with ROADRECON-85B agree with each other at a 95% confidence level (Fig. C.13). Thus, it can be concluded that the PASCO system can repeat itself satisfactorily with a 99% confidence level, except in the laser system, which probably can repeat itself with a 95% confidence level.

The "t" = 4.8 with 17° of freedom indicates that MCI values obtained by PASCO and PSI values obtained by Iowa DOT correlate well at a 99% confidence level or better. At "t" > 2.5 the correlation for determining the rut depth, patching, and roughness by Iowa DOT and PASCO agrees at 95% confidence level or better.

The correlation for determining cracking by Iowa DOT and PASCO methods gives t = 1.18 with 12° of freedom. This indicates an agreement only at about the 70% confidence level. This lower level may be due to hairline cracks that are included in the PASCO method. Strip photography is considered capable of precisely determining the cracks, whereas crack measurements made by "walking" the pavement are very subjective.

Costs and Productivity

According to the Iowa DOT, the cost of a roughness survey is about \$187 per two-lane mile including \$8.43 per two-lane mile for a crack and patch survey. The cost for the PASCO method varies from \$150 to \$300 per survey mile depending on the miles surveyed.

The Iowa DOT took five days to perform the survey, whereas PASCO took four nights and one day to collect the data. The office work (computation and analysis) by Iowa DOT is fairly simple and fast. The office work by PASCO is precise and time consuming. It took more than five weeks for PASCO to give the results, but these included a number of graphs, plots, photographs, and the like. Even so, PASCO should be commended for having completed the work within five weeks.

Two operators and a supervisor were involved in collecting the data for the PASCO system. Two technicians from Iowa DOT were involved in collecting the data for the Iowa DOT method. The computations for Iowa DOT were done in Ames, Iowa, by qualified engineers. According to PASCO the computations for PASCO methods were done in Tokyo, Japan, by qualified engineers and technicians. Trained engineers are needed to collect the data for the PASCO method, whereas in the Iowa DOT method the data collection can be done by technicians.

Speed of Data Collection

The speed of data collection was illustrated by the manufacturer in Table 4. The slit camera and pulse camera performed satisfactorily at both high speed (40 mph) and low speed (25 mph). At complete stops, the slit camera tended toward overexposure and thus allowed the possibility of some data loss at traffic lights. The tracking wheel was operated only at a maximum speed of 40 km/hr (25 mph), whereas the laser was operated at both high and low speeds. The performance of the laser at low speed was slightly below satisfactory (95%).

Potential Uses of the PASCO System

When the PASCO and Iowa DOT systems are compared, the slit and pulse cameras of the PASCO system appear to be a definite improvement over the cracking and patching measurement system of the Iowa DOT. However, implementation of the PASCO system requires the purchase of expensive equipment (slit camera, pulse camera, automatic film processor, enlarger with digitizer, comparator or analytical plotter, etc.) and the training of personnel on the proper use of the equipment.

The tracking wheel of the PASCO system is similar to the BPR method of the Iowa DOT in that it is a contact device to measure roughness. However, the tracking wheel, unlike the BPR method, has the facility to record the data continuously on a cassette tape and display it on a paper chart. The evaluation team did not have access to the tapes and therefore cannot make any comment on its potential use.

The laser system, a noncontact device, appears not to be fully developed. Upon its satisfactory development, it has the potential of replacing the BPR.

Potential Modifications

The PASCO system was evaluated in three different modes:

1. Slit camera and laser
2. Pulse camera and laser
3. Tracking wheel.

Ideally, the system should allow simultaneous operation of the pulse camera, slit camera, and tracking wheel or laser. Thus, it is recommended that the PASCO system be modified such that the slit camera is mounted in front of the vehicle and the pulse camera behind the vehicle. This modification will not only allow simultaneous data collection but will also help in precisely locating the position of the pulse camera exposure.

The data collected on the cassette tape can only be analyzed by a computer similar to the one on board the PASCO vehicle. However, if this form of storage can be made compatible with a personal computer such as the IBM PC, then the data can be easily analyzed in the office.

Accuracy of Measurements

When the slit camera is used, any cracks and patches larger than 0.5 in. × 0.5 in. (1 cm^2) in area can be easily identified and measured. However, cracks and patches 0.05 in. (1 mm) wide or wider can also be easily identified.

When the pulse camera is used, the rut depth can be plotted with an accuracy of 0.5 in. (± 1 mm). However, the control for measuring the rut depth is subjective.

The tracking wheel can measure roughness with an accuracy of 0.05 in. (± 1 mm). The paper chart, however, is not convenient for measurement. In addition, while the TCR count on the paper chart is essential, the data on cassette tape can be processed later.

The laser can measure roughness with a resolution of 0.01 in. (0.4 mm). The paper chart in the laser system did not have a TCR count; as a result, accurate measurement could not be made, manually, on the paper chart. Since the roughness is required to the nearest inch per mile, an accuracy of 0.05 in. per measurement may be required; this is difficult to measure on a paper chart.

PASCO Applications in Iowa

If the PASCO system can be modified so that the pulse camera, slit camera, and laser are all operational simultaneously, then PASCO could replace the present Iowa DOT system. However the present BPR method of the Iowa DOT seems to be accurate and efficient. The use of the pulse and slit cameras could enhance the Iowa DOT's capability to monitor accurately cracking, patching, and rutting. Replacement of the BPR method by a laser is not indicated until a laser system that offers satisfactory performance is developed.

6. MANUAL DISTRESS SURVEY METHODS COMPARISON

The use of manual methods to assess pavement conditions has progressed to a great degree because of the emphasis on pavement management and the rehabilitation needs of the highway systems in Iowa and the nation. The crack and patch survey used by Iowa originated with the famed AASHO Road Test in the late 1950s. The advent of pavement management systems and the emphasis on pavement rehabilitation research by the federal government and the highway industry in the 1970s brought about new techniques for the measurement of pavement conditions.

Three such manual survey methods were reviewed for their use of the output of the PASCO ROADRECON systems to provide a source of input data. They included the following:

1. Highway Pavement Distress Identification Manual for Highway Condition and Quality of Construction Survey (March 1979)
2. Pavement Condition Rating Guide (September 1985)
3. SHRP/LTPP Identification Manual (September 1986)

The attributes of each method are further described in the following sections.

Highway Pavement Distress Identification Manual [Smith and Darter 1979]

This manual was produced as part of NCHRP 1-19/DOT-FH-11-9175 to standardize the identification of the distress types associated with four types of conventional pavements. The pavement types included jointed plain concrete, jointed reinforced concrete, asphalt-surfaced granular or stabilized base, and asphalt overlays of portland cement concrete. The distress definitions were developed from an airfield distress identification manual by Shahin, Darter, and Kohn [1976] and the "Standard Nomenclature and Definitions for Pavement Components and Deficiencies" section from Special Report 113, Highway Research Board, as well as extensive field surveys and discussions with state highway engineers.

The effectiveness of the plan centered on the use of photos of actual field pavements to define the types of distress and the levels of severity. The pictures were used by trained observers of related field conditions on statistically selected sections to determine network and project level pavement deficiencies. This method of condition survey requires the use of trained observers, the manual of pictures, the subdivision of the construction projects into 1-mi test sections and 0.1-mi sample sections, and a set form to record the data.

Pavement Condition Rating Guide [Zaniewski and Hudson 1985]

The guide was a response to the needs of the states for new procedures to meet the needs of developing pavement management systems and the needs of the federal government to provide pavement rehabilitation information to Congress. The Federal Highway Administration implemented the Highway Performance Monitoring System to provide a statistical sample of the financial needs and current conditions for the nation's federally supported road system. The guide provided procedures to assess both pavement condition and serviceability for both network and project levels.

Photographs were used in the same manner as the Highway Pavement Distress Manual to identify the types and severity levels of each distress type without the use of new terminology or evaluation procedures. The guide provided ways to combine some of the distresses to make the process of data collection less difficult for inexperienced personnel. This approach was designed to reduce the time and cost of data collection. The data were entered on special data forms in the field and collected by trained crews from sample sections selected in a manner similar to that of the Highway Pavement Distress Manual.

A new concept for the calibration of roughness was added in this manual: measuring the longitudinal profile by mechanical means and relating it to the present serviceability rating applied by a human panel. It was based on the work of Carey-Irick from the AASHO road test. It combines the theory of ride and distress measurements such as cracks and patches to describe the serviceability in terms that the vehicle operator would use. Combinations of distress types and use of photographs provide a more detailed method of condition surveying and at the same time reduce the time and cost of the work.

Distress Identification Manual for the Long-Term Pavement Performance (LTPP) Studies [Smith et al. 1986]

The manual was developed for the Long-Term Pavement Performance (LTPP), Asphalt Characteristics, Maintenance Cost Effectiveness, and Cement and Concrete Studies emphasis areas of the Strategic Highway Research Program (SHRP). The format for the data collection was based on the results of pilot data collection efforts by eight states including Iowa. The actual plan was developed as part of the transition plan for SHRP from the pilot study activities to the LTPP effort for the nationwide data collection over the planned 20-year period.

The objectives of this manual include improving the definitions, improving identification procedures, and establishing severity levels for the various distress types. The manual's primary purposes are to develop a uniform basis for the collection of distress data during the LTPP effort and to form an international data base for evaluating and understanding pavement performance on a consistent basis.

Four basic types of pavement--including asphaltic concrete, jointed plain concrete, jointed reinforced concrete, and continuously reinforced concrete--are measured for condition. The asphalt surfaces include overlays of portland cement, and the concrete pavements include bonded and unbonded overlays of portland cement. The manual relies heavily on the Highway Pavement Distress Identification Manual for Highway Condition and Quality of Construction Survey for the asphalt-surfaced pavement distresses, and on the Portland Cement Concrete Pavement Evaluation System (COPES), NCHRP Report No. 277, for the concrete-surfaced pavement distresses. Pavement distress types and severity levels are again established by using photographic references and trained observers.

This report includes references to future enhancements, not shown in the other reports, to the data collection effort by using high-speed photography and electronic measuring techniques. The report anticipates the use of laser disk storage/retrieval of data and the use of equipment such as the ROADRECON camera system or video cameras to provide improved resolution for distress measurement. Measurement of the distresses noted would be accomplished by the use of video monitors with superimposed grids for trained operator analysis. The report notes that some of the distresses will not be measurable through photographs; alternate methods, as yet unidentified, will be required.

Manual Method Comparison

Each of these reports identifies methods of data collection for a particular purpose. They do contain certain common elements. Each method uses photographs and verbal means to define the type of distress and the level of severity. Definitions of distress are basically the same in each of the manuals, and the differences occur only in the magnitude of the physical measurement defining severity. Currently, each method can be used in a manual analysis with specially developed survey forms and trained observer teams. The field data can then be coded for electronic data entry and analysis. The majority of distress types are applicable to the use of high-speed photography where the extent of distress is measured in units of area or length. Items such as rutting, bleeding, and lane-to-shoulder edge dropoffs on asphaltic concrete pavements are not considered applicable to photographic analysis in the reports. Similar statements can be made about the faulting and lane-to-shoulder dropoffs and separations in portland cement concrete pavements.

ROADRECON Application

The ROADRECON series is applicable for measuring each of the items shown in the manuals where identification involves a measure of the presence or absence of the distress, a measure of the area covered by the distress, or the length of the particular distress.

The use of the artificial light source allows the ROADRECON equipment to provide an adequate view of the bleeding in asphalt to show the extent of the area covered.

The use of the pulse camera provides a measure of the amount of rutting by using the pavement edges as reference points. In this way the actual amounts of heaving and rutting can be measured. The results will not match the manual methods where only a four-foot straight edge is used, because of the heaving effect at the center of the lane. The ROADRECON method provides a more accurate way of measuring the actual cross section of the road and a better understanding of the reasons behind movement in the section over time.

Lane-to-shoulder dropoff dimensions can be obtained by use of the slit camera and operation on either the shoulder or the driving lane of the pavement. The photograph of the lane-shoulder area can be used to measure the dropoff and the presence or absence of a separation.

The ROADRECON system has the ability to measure faulting through the use of the lasers mounted in the longitudinal position. In this position, the longitudinal profile could be used to indicate the relative position of the slabs at the joints. That particular aspect of the equipment was not evaluated in this study.

ROADRECON equipment is capable of measuring the width of cracks and lane shoulder separations through the enlargement of the photographs. Each of the manual methods includes severity threshold measures of cracks of either one-quarter or one-half-inch width. This type of measure from the films requires enlargement of the area for manual measurement with the grid overlay or mechanical measurement of the enlarged area by the computer.

Constant light source intensity and night operations are extra advantages of the ROADRECON system. The film can be analyzed by use of a grid overlay to measure the extent of the distress over the entire road section rather than a sample section. The successive runs over the same sections with the use of physical milemarker references can provide a measure of the rate of distress development of various types. This has been difficult to do with conventional photographs and sample areas because of the angle of the light source and the location of the area on the actual highway. The results provide detailed information on the amount and location of various types of rehabilitation needs.

7. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The evaluation shows that the PASCO method and equipment can provide not only the same level of information provided by current Iowa DOT methods but also can improve on the quality, amount, and use of the resulting data. The MCI values obtained with the PASCO equipment agree with the Iowa DOT PSI results for the test sections within the 95% confidence level when the wheel device for measuring longitudinal profile is used. Similar results are shown for the use of the photographic equipment to measure rut depth and patching.

Repeatability of performance in each of the measurements on successive runs over the test sections resulted in a 99% confidence level attainment for all items except the laser measurements, which resulted in a 95% confidence level. The accuracy of laser measurements can be improved by the use of computer analysis.

It is difficult at best to compare statistically subjective versus objective data measurements regarding pavement condition ratings. Without bias for validity of either method, the PASCO and Iowa DOT crack measurements were compared. Test results indicate that the correlation for the cracking measurements between the two methods is in the 70% confidence level. This is due to the ability of the PASCO unit to measure all cracks in the test section rather than the smaller DOT one-half-mile sample section, to observe the site vertically under constant light, and to characterize the cracks into distress types and sizes for the measure of severity. Enlarging the sample area and improving the measurement precision represents an enhancement over current Iowa DOT methods.

The confidence levels reached in the comparison and repeatability of measurements between methods are sufficient at the 95%-99% levels to meet the needs of the Iowa DOT. The variations in the rut depth, cracking, and laser measurements are due to the increased accuracy of measurement in the PASCO unit and will improve the Iowa DOT data as a result of the repeatability confidence levels attained.

The costs of data collection and analysis for the two methods are nearly equal when sufficient volumes of road miles are analyzed in the test year. The DOT costs for collection and analysis of the ride, rut, and crack and patch data range from $98 to $187 per two-lane mile depending on the number of crack and patch surveys conducted. The PASCO figures for the same work indicate that the costs are estimated to range from $150 to $300 per two-lane mile depending on the volume of business. When assuming that all the items of data could be conducted on 5,000 miles of road in Iowa annually, it appears to be quite possible that the work could be accomplished for $125 to $150 per two-lane mile. This would be an enhancement over the current goal of providing ride data on one-third (3,300) of the miles annually and crack and patch data on one-half of the system annually.

Rate of data collection is difficult to evaluate for a small number of test sections. Normal operations of both the PASCO and DOT units are designed for continuous operation. The limited scope of work in this evaluation indicates that the PASCO organization operating with one unit and two to three operators can gather data equally as fast or faster than the DOT using five vehicles and three to six persons to perform the two operations. The ability to operate in traffic with one vehicle versus several and with no personnel performing work on the pavement surface is an advantage in terms of safety. The ability of the PASCO unit to operate at night provides an additional benefit in its ability to maintain a constant speed through municipalities during data collection, because with night traffic conditions interference is reduced.

The current disadvantage in the PASCO analysis involves the reduction of the film data to usable reports. The work is accomplished by trained personnel in Japan and consumes three to five weeks. DOT analysis is accomplished in a matter of days at the central office via direct entry of much of the data from field terminals.

The cost of data collection and analysis for the two methods is nearly equal when sufficient volumes of road miles are used in the test year. The DOT cost for collection and editing of the ride, rut, and crack and patch data ranges from $98 to $187 per two-lane mile, depending on the number of crack and patch surveys conducted. PASCO has estimated the following leasing costs to provide similar two-lane information:

1. Longitudinal profile computer tape or paper prints: $30 per two-lane mile (ROADRECON-77 or 85)

2. Rut-depth strip photo negatives: $50 per two-lane mile (ROADRECON-75)

3. Crack and patch strip photos (ROADRECON-70): negatives $110 per two-lane mile; positives $130 per two-lane mile.

Prices are based on collecting data on 150 lane-miles per night of operation. Assuming that positive photos are necessary for analysis in Iowa, the data collection costs would be \$220 per two-lane mile (130 + 60 est. + 30) to obtain PASCO services. PASCO estimated \$200 per two-lane mile if negatives are used and indicated that a reduction of up to \$20 per two-lane mile was possible for volume work. If we assume an eight-hour collection time and 40 mph average speed including downtime to change film, some 320 lane miles can be filmed per night. If 50 mph were attained as the manufacturer attests, 400 lane-miles can be covered. If 350 lane-miles are covered including meal stops, this is over twice the base mileage and should result in a savings of 10%-15% to the state. At a 15% savings (0.85 × \$220) the current Iowa method and the PASCO method are nearly equal in cost, excluding any data analysis.

PASCO provided data reduction to an MCI value with special reports for this study. Iowa does not compute an MCI, only a PSI including rut, crack and patch values, and profile values. PASCO has estimated the following costs to provide MCI reports:

1. Cracking area: \$70 per two-lane mile
2. Rutting averages by lane over the length of the section: \$40 per two-lane mile
3. Longitudinal profile reduction: \$20 per two-lane mile.

In total this equals \$130 per two-lane mile.

Consideration of analysis costs with PASCO data (at a minimum) provides Iowa with two new options. Both involve the use of a trained observer to analyze the data as a quality control on the field data collection and to provide uniformity of results. This observer would become an expert in the evaluation of the condition of the pavement system for the development of performance prediction models.

Assuming a technician is employed either full or part time on film review, we considered two strategies. The first assumes data collection on one-half of the primary road system annually (5,000 two-lane miles), use of the current one-half mile per project test sections for distress review measurements, and a three-lane mile per hour viewing rate. The second considers continuous viewing at the same rate over the complete section and with a full-time position is limited to 3,000 two-lane miles per year of data collection. Each assumes costs for the trained observer and the cost of video laser disks. The costs of transferring the film data to disk and the playback equipment are assumed to be covered by a separate research project. Alternative one will add approximately $2 per two-lane mile and alternative two will add $11 per two-lane mile to Iowa's total cost. For less than a one percent increase in costs, Iowa could use the PASCO system and its own improved analysis to improve the accuracy and repeatability of pavement management data.

The slit and pulse cameras performed well at speeds ranging from 25 mph to 55 mph. Minimal overexposure of film from the slit camera was encountered when the unit was stopped at a traffic signal. The factor limiting the speed of travel in the evaluation is the measure of longitudinal profile and the route speed limits. We were able to test successfully the tracking wheel system to a maximum range of 40 mph. The laser system was tested successfully at both urban speeds of 25 mph and rural speeds of 55 mph.

Both methods of measurement that were evaluated experienced no mechanical difficulties and only minutes of setup time to prepare for data collection.

The slit camera was able to measure accurately cracks 0.05 inches wide and patches 0.5 in.^{2} or larger. Tracking wheel roughness measurements were made with an accuracy of ±0.05 inches, while the laser is capable of measuring to ±0.01 inch. This represents an enhancement over the current accuracy of an inch in the DOT measurements.

The PASCO system represents a way of mechanizing the data collection process for the DOT at an affordable price and without sacrificing the historical data collected by current methods. It provides an opportunity to free field and office personnel from crack and patch surveys for other more urgent duties. It also serves as a transition process to move from manual methods of data collection and analysis to automated objective data collection and a single, trained-observer analysis of pavement distress. The goal of automated collection is to use computer analysis of the pavement condition with quality control provided by the pavement management staff. This in turn will assist the DOT in removing much of the subjectivity from the condition analysis and in improving the objectivity of the information provided to top management for pavement rehabilitation decisions.

Recommendations

1. The DOT should investigate the feasibility of obtaining the PASCO equipment or services and the establishment of a program to begin using the method to obtain and analyze the pavement condition of the primary highway system.

2. PASCO should investigate the possibility of providing the following services in conjunction with their present equipment:

   a. Videotaped alternatives to the current 35-mm film systems.

   b. Laser disc data storage to provide instant playback of the data.

   c. Film reduction and analysis operations in the state in which the data is collected or at the New Jersey facility to reduce time delays.

   d. Provision of onboard, IBM micro-computer-compatible, editing capabilities.

3. PASCO should outfit the unit with the slit camera, pulse camera, and the laser equipment for simultaneous data collection capability and economical operation. The tracking wheel sensor is an option but limits the speed of operation. Disk storage for the data and computer analysis of the results to use the ±0.01-inch accuracy possible should also be provided.

4. PASCO should continue the development of the laser measurement systems to provide ride data collection at highway speeds in order to repeat the effect identified by the vehicle operator.

5. Additional research has been identified:

   a. Evaluation of the pulse camera accuracy in measurement of the rut depth versus conventional measurements.

b. Evaluation of the laser system against other methods of measuring longitudinal profile.

c. Comparison of the capabilities of the slit camera versus the use of video cameras in the measurement of pavement surface distress.

Potential Uses of PASCO

The PASCO system offers potential for use at three levels of government. The first application is with the consulting firms in the analysis of county and city pavements for rehabilitation projects. One pass of the full ROADRECON system can gather both visual and numerical data on which to base design decisions.

At the state level the system provides the bridge between the use of manual methods, which employ various levels of subjectivity, and the use of fully automated, objective review of pavement condition for rehabilitation decisions. It allows the existing personnel to be diverted from survey work to more important tasks. In Iowa it can be used not only for pavement management inventory tasks but also for analysis of detours and construction haul routes before and after use. In addition, it can provide visual and numerical information for the design of project plans for detailed pavement rehabilitation.

In Iowa, the PASCO unit can serve to replace several outdated pieces of equipment currently used to monitor pavement condition. Increased efficiency in data collection and reliable repeatability of data are available in the PASCO unit. This unit would also serve to provide a replacement for the photologging van if an additional camera could be mounted with a forward view of the roadway. This additional camera would provide a view of the pavement and road environment simultaneously to answer both safety and design questions, and at the same time it would reduce the number of personnel required to obtain the data.

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APPENDIX A: DESCRIPTION OF DOT SYSTEMS

Test Method No. Iowa 1001-A
May 1970

IOWA STATE HIGHWAY COMMISSION

Materials Department

METHOD OF TEST FOR B.P.R.

TYPE ROAD ROUGHNESS MEASUREMENT

Scope

The road roughness indicated by this method is a comparative index expressed as inches of roughness per mile of driving lame tested.

The surface test provides a measure at 20 miles per hour with summation of one way movement of standard towed trailer built in accordance to plans originally drawn by the Bureau of Public Roads Administration in 1941, and revised at various later dates.

Procedure

A. Apparatus

1. Towing vehicle with accurate tachometer for speed control.

2. Roughometer trailer consisting of a frame, integrator, and a standard 6.70-15" automobile tire.

3. Electrical components.

   a. Revolution counters in towing unit.

   b. Integral counter on vertical movement.

   c. Duplicate sets of counters with switch over to change counters for recording facilities without stopping, and a master switch.

4. Signs and rotating beacons on trailing vehicles in accordance with Traffic and Safety minimum requirements.

B. Test Record Forms

1. Use work sheet labeled, Road Roughness Measurement, Field Work Sheet, for recording field measurements.

2. For Laboratory final report, the form is labeled Road Roughness Report.

C. Test Procedure

1. Stop and remove trailer wheels from single wheel roughometer.

2. Engage wheel revolution counter and integrating roughness counter.

3. Check the damping fluid level in the damping pots, and add if needed.

4. The entire unit must be warmed up prior to testing a pavement section for roughness. Check tire inflation (27 p.s.i.) before and after warm-up period. The warm-up period consists of towing the unit at a speed of 30 mph. for a distance of approximately 10 miles with the counters turned on for the last two miles. A longer period is required during cool weather.

5. Set the roughometer counters and wheel revolution counters to zero ready for a start on test section, with the vehicle far enough from the beginning of the section to safely accelerate the vehicle to a constant 20 mph. speed, before reaching the test section. Maintain this speed for all tests.

6. Turn on the master switch at the beginning of the test section. Omit bridges and railroad tracks during the actual test run, by switching the master switch off and on at the proper times.

7. During the run through the project, the predetermined sections within the project are checked by the recorder, switching from one set of counters to another, when the revolution counter shows the proper interval. The usual normal section length is predetermined by the following rule:

No. of Miles In Project	No. of Revolutions in Sections (*)	Appropriate Chosen Interval (Mi.)
Less than 2.0	186	1/4
2.0 to 5.0	372	1/2
Greater than 5.0	744	1

* Note: Based on present calibrated rate of test tire revolutions per measured mile with 27 p.s.i. tire pressure.

The above rule is followed unless a special request is made to have the reading units changed on a certain project, or by the recorder noticing an exceptionally rough section that he wishes to isolate in the notes, or report as a special section. Keep the units in each two lane roadway identical as to stationing from beginning to end of section.

D. Reporting Results

1. The field work sheet provides places to note the project number, contractor, actual number of miles in project, weather conditions, description of location and the tested section itself. Testing personnel are reported along with visiting personnel riding as observers. Starting locations are recorded with readings and section lengths. The remarks column is used to help describe any special events, conditions, etc.

Fig. 1
Roughometer in Towing Position

E. Normal Check Calibrations

1. Each year all the bearings on the trailer unit including spring bearings are to be cleaned, checked regreased and renewed as required. The tire is also to be checked for roundness to .010" maximum variation. The center of percussion is checked on unit, and adjusted by changing balance weights on frame if necessary.

2. Before each week of operation, a check over standard measured courses is made to determine if counters, integrators and dash pots are performing properly. If at any time during the weeks work the operator feels that the results are not correct, an extra check may be made

F. Precautions

1. The Resident or County Engineer must be notified before arriving on his project for testing, so that he may have the work readied for testing, and to arrange for any observers to accompany the testing crew.

2. Temperatures below freezing may affect the integrator by reducing its sensitivity to slip and grab in its check of slight movements.

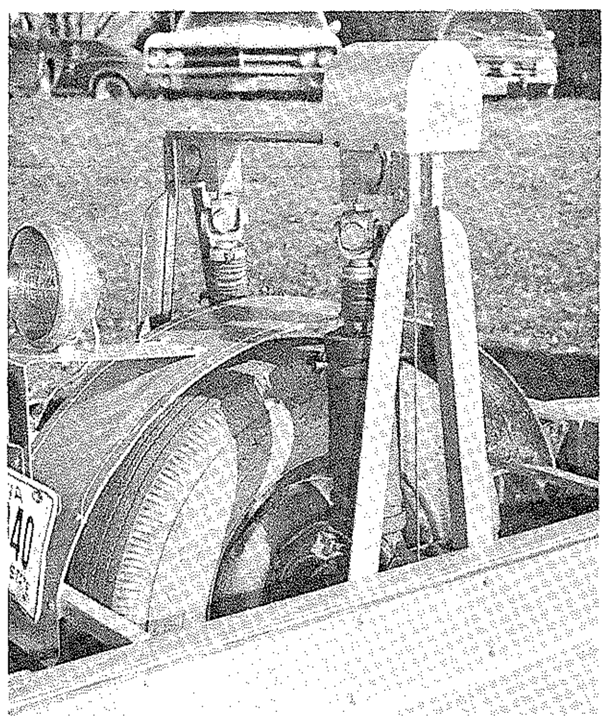

Fig. 2
Close-up of Roughometer

Test Method No. Iowa 1002-B
March 1976

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION

Office of Materials

METHOD OF DETERMINATION OF LONGITUDINAL PROFILE VALUE USING THE IJK RIDE INDICATOR

Scope

This testing method is used to determine the Longitudinal Profile Value (LPV) using the IJK Ride Indicator. The Longitudinal Profile Value is used to determine the Present Serviceability Index (P.S.I.), a concept developed by the American Association of State Highway Officials (AASHO) Road Test. It (P.S.I.) is used as an indicator of the ability of a pavement to serve the traveling public and as an objective method of highway evaluation.

The IJK (Iowa-Johannsen-Kirk) Ride Indicator was developed by the Iowa Department of Transportation Materials Laboratory.

Procedure

A. Apparatus

1. IJK Ride Indicator (An electro-mechanical device mounted on the differential of a standard automobile)(Fig. 1 to 4).
2. Tire pressure gauge.
3. Portable calculator.

B. Test Record Forms and Section Identification

1. Longitudinal Profile Value Worksheet (Form 921).
2. Final Report (Forms 915 or 922).
3. "Test Sections by Milepost" booklet.
4. Correlation Table (Longitudinal Profile Value vs. Sum/Length for testing unit).

C. Personnel

1. Two personnel are required. One is assigned to drive while the other operates the counters and makes calculations.

D. Correlation

1. The Longitudinal Profile Value is derived from equations of the AASHO Road Test using a correlation between the CHLOE Profilometer and the IJK Ride Indicator. The CHLOE is used as a correlation standard because it is not affected by possible changes in suspension but primarily is dependent only on proper electrical operation. The relationship between the CHLOE and the IJK Ride Indicator is determined through a computer program by the least square parabolic method ($Y=CX^2+MX+B$).

E. Test Procedure

1. Drive the test vehicle at least 10 miles before beginning testing.
2. Operate the vehicle in a careful, legal, conscientious manner.
3. Be sure the IJK unit is accurately zeroed before mounting on the vehicle.
4. Be sure the dampening fluid level is correct. This should be checked weekly during continuous operation.
5. During continuous testing, the unit should be tested on eight conveniently close correlation sections weekly to verify proper operation.
6. When ready to begin testing, disengage the IJK arm lock.
7. Start the test vehicle far enough from the beginning of the test section to insure adequate distance for acceleration to the standard test speed of 50 MPH. Turn the main switch to the "ON" position as the rear wheels pass the start of the test section. It is turned off in the same position at the end of the section.

8. Turn the main switch off while crossing railroad tracks and bridges (including approaches). This length and roughness counts are electrically omitted.

9. There is a rotary switch to change from one bank of recording counters to the other so testing can be continuous.

10. Record the counter values and calculate the Sum/L.

11. If there is some reason to indicate possible erroneous data a repeat run should be made. Valid runs are expected to check within 10% of each other.

12. Using the Sum/L, obtain the proper Longitudinal Profile Value from the table to the closest 0.05 (3.95, 4.15 etc.).

F. Precautions

1. Maintain the tire pressure at 25 psi cold, 28 psi, warm. If any tire alignment or balancing problems are noted, have them corrected.

2. Be sure to engage the IJK arm lock when not testing.

3. Keep the vehicle in a neat orderly condition.

4. Have the automobile serviced at the proper interval.

G. Calculations for Longitudinal Profile Value

1. Enter the necessary descriptive data in the heading portion of the LPV worksheet. The method of calculation is as follows: the summation of counts from counter no. 1 x 1, counter no. 2 x 2, counter no. 3 x 3, etc. These products are totaled and divided by the tested length (in miles) to obtain the Sum/L. This sum/length is then used to find the Longitudinal Profile Value from the correlation table.

H. Reporting Results

1. The final report for all testing uses the same data that was necessary for the worksheet. Form 915 is used for county inventory testing and Form 922 is used for testing individual projects. A deduction for cracking, patching and rut depth is used (from the most recent survey) to yield a Present Serviceability Index.

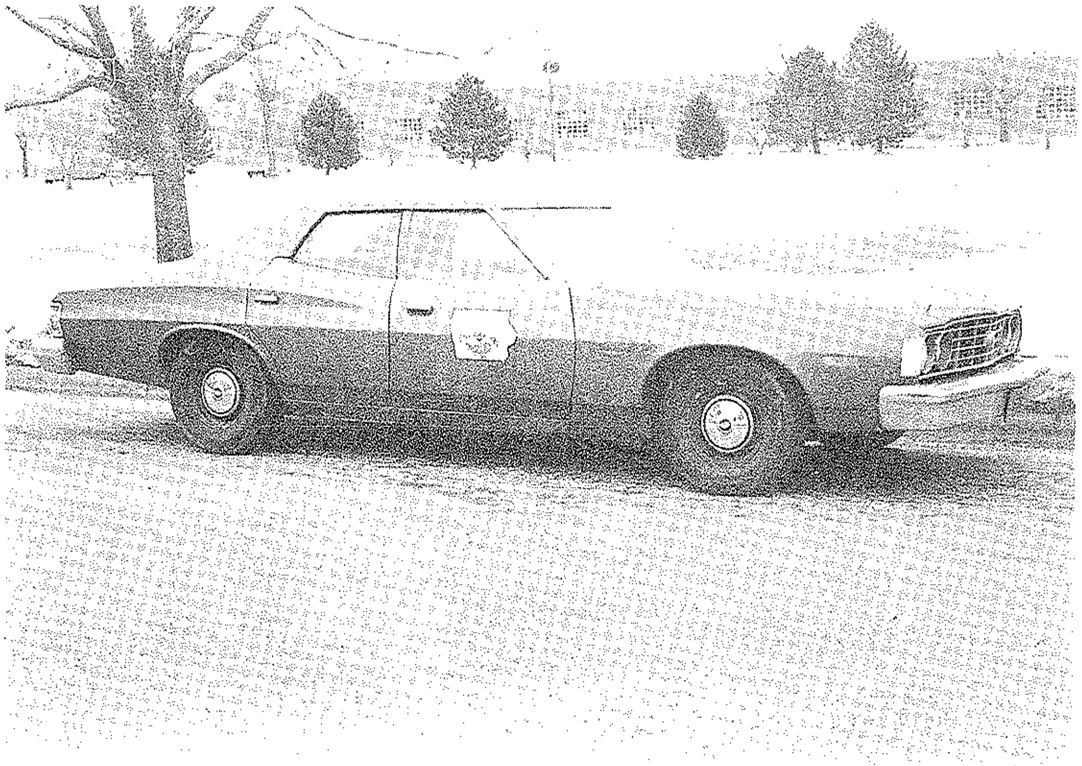

Fig. 1

The IJK Ride Indicator Vehicle

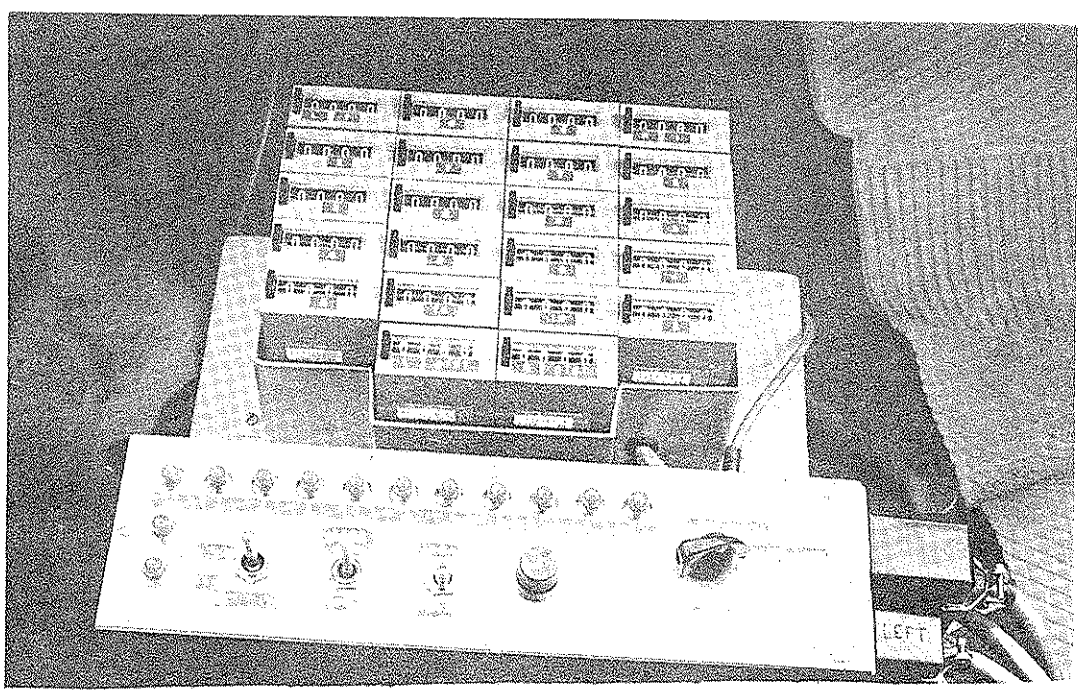

Fig. 2

The IJK Ride Indicator Control Console, showing Visual Indicators, Switches and Electrical Counters on the floor of the automobile.

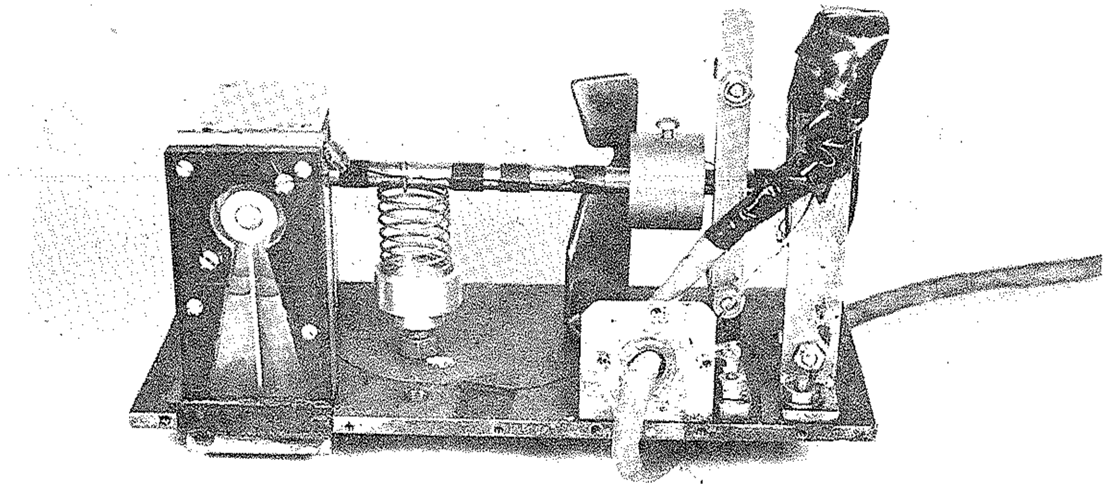

Fig. 3

The IJK Ride Indicator Sensing Unit

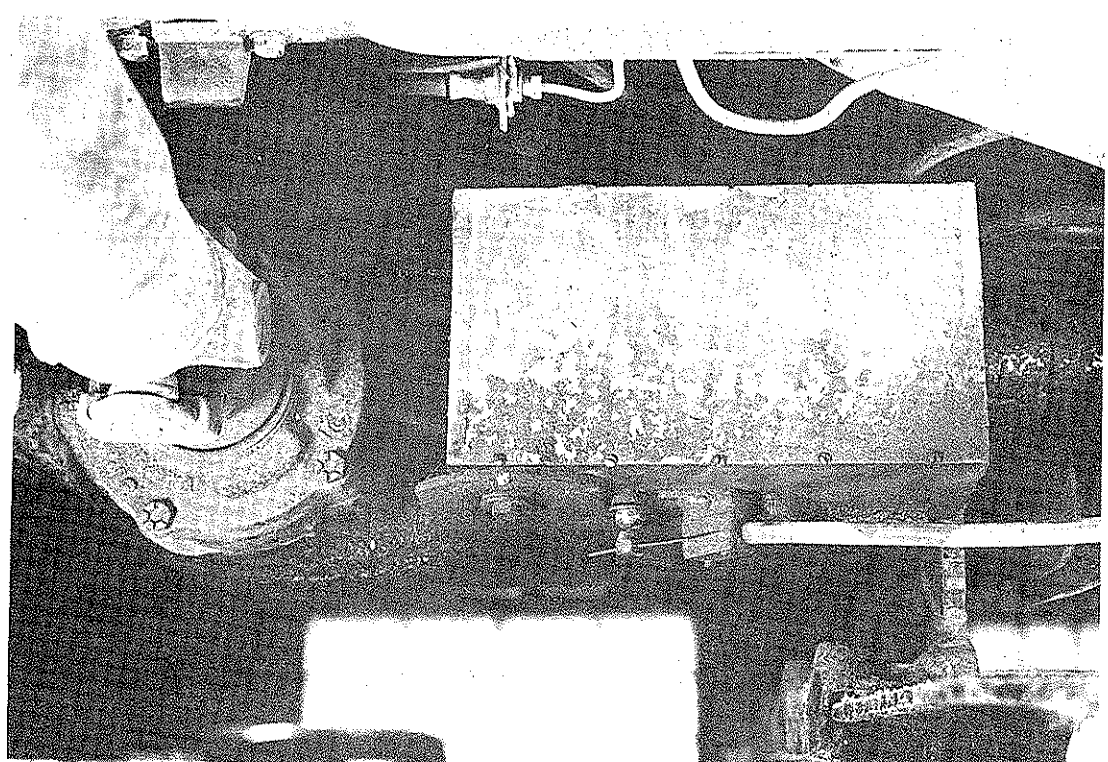

Fig. 4

The IJK Ride Indicator Sensing Unit with Cover as Mounted on the Rear Differential Housing of the Vehicle

CORRELATION TABLE
IJK RIDE INDICATOR UNIT E
JULY 1975

	SUM/LENGTH			SUM/LENGTH			SUM/LENGTH	
LPV	AC	PC	LPV	AC	PC	LPV	AC	PC
0.000	18770	29785	2.000	4449	7023	4.000	502	985
0.025	18462	29283	2.025	4369	6886	4.025	481	952
0.050	18159	28790	2.050	4272	6750	4.050	460	920
0.075	17860	28304	2.075	4185	6617	4.075	440	889
0.100	17566	27825	2.100	4100	6486	4.100	420	858
0.125	17276	27355	2.125	4016	6357	4.125	401	828
0.150	16991	26891	2.150	3933	6231	4.150	382	799
0.175	16710	26435	2.175	3852	6106	4.175	364	770
0.200	16433	25987	2.200	3772	5984	4.200	346	742
0.225	16160	25545	2.225	3693	5863	4.225	328	715
0.250	15892	25111	2.250	3615	5744	4.250	311	688
0.275	15628	24684	2.275	3539	5628	4.275	294	661
0.300	15367	24263	2.300	3464	5513	4.300	277	635
0.325	15110	23849	2.325	3391	5400	4.325	261	610
0.350	14858	23441	2.350	3318	5290	4.350	245	585
0.375	14609	23041	2.375	3247	5181	4.375	230	561
0.400	14364	22646	2.400	3176	5073	4.400	215	538
0.425	14122	22258	2.425	3107	4968	4.425	200	515
0.450	13885	21876	2.450	3039	4864	4.450	186	492
0.475	13650	21500	2.475	2973	4762	4.475	172	470
0.500	13420	21130	2.500	2907	4662	4.500	158	448
0.525	13193	20766	2.525	2842	4563	4.525	145	427
0.550	12969	20407	2.550	2779	4467	4.550	132	407
0.575	12749	20055	2.575	2716	4371	4.575	119	387
0.600	12532	19708	2.600	2655	4278	4.600	107	367
0.625	12318	19366	2.625	2594	4186	4.625	94	348
0.650	12107	19030	2.650	2535	4095	4.650	83	329
0.675	11900	18700	2.675	2477	4006	4.675	71	311
0.700	11696	18374	2.700	2419	3919	4.700	60	293
0.725	11495	18054	2.725	2363	3833	4.725	49	275
0.750	11297	17739	2.750	2307	3748	4.750	38	258
0.775	11102	17429	2.775	2253	3665	4.775	27	242
0.800	10910	17124	2.800	2199	3583	4.800	17	225
0.825	10721	16824	2.825	2146	3503	4.825	7	210
0.850	10534	16529	2.850	2095	3424	4.850	1	194
0.875	10351	16238	2.875	2044	3347	4.875		179
0.900	10170	15952	2.900	1994	3270	4.900		164
0.925	9992	15670	2.925	1944	3196	4.925		150
0.950	9817	15393	2.950	1896	3122	4.950		136
0.975	9645	15121	2.975	1849	3050	4.975		122
1.000	9475	14853	3.000	1802	2979	5.000		109
1.025	9308	14589	3.025	1756	2909	5.025		96
1.050	9143	14329	3.050	1711	2840	5.050		84
1.075	8981	14074	3.075	1667	2773	5.075		71
1.100	8821	13822	3.100	1624	2707	5.100		59
1.125	8663	13575	3.125	1581	2642	5.125		48
1.150	8509	13332	3.150	1539	2578	5.150		36
1.175	8356	13092	3.175	1498	2515	5.175		25
1.200	8206	12856	3.200	1458	2454	5.200		14
1.225	8058	12625	3.225	1418	2393	5.225		4
1.250	7912	12396	3.250	1379	2334			
1.275	7769	12172	3.275	1341	2275			
1.300	7628	11951	3.300	1303	2218			
1.325	7489	11734	3.325	1267	2162			
1.350	7352	11520	3.350	1231	2107			
1.375	7217	11309	3.375	1195	2052			
1.400	7084	11102	3.400	1160	1999			
1.425	6953	10899	3.425	1126	1947			
1.450	6825	10698	3.450	1093	1896			
1.475	6698	10501	3.475	1060	1845			
1.500	6573	10307	3.500	1028	1796			
1.525	6451	10116	3.525	996	1748			
1.550	6330	9928	3.550	965	1700			
1.575	6211	9744	3.575	935	1653			
1.600	6094	9562	3.600	905	1608			
1.625	5978	9383	3.625	876	1563			
1.650	5865	9207	3.650	847	1519			
1.675	5753	9034	3.675	819	1475			
1.700	5643	8863	3.700	791	1433			
1.725	5534	8696	3.725	764	1391			
1.750	5428	8531	3.750	738	1351			
1.775	5323	8369	3.775	712	1311			
1.800	5220	8209	3.800	687	1272			
1.825	5118	8052	3.825	662	1233			
1.850	5018	7898	3.850	637	1196			
1.875	4919	7746	3.875	614	1159			
1.900	4822	7597	3.900	590	1123			
1.925	4727	7450	3.925	567	1087			
1.950	4633	7305	3.950	545	1052			
1.975	4540	7163	3.975	523	1018			

Form 921

Test Method No. Iowa 1002-B
March 1976

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION
OFFICE OF MATERIALS

Unit E Worksheet

Road No. I-35 County Story Lab. No. LV
Year Built Date Tested 7-29-69 Date Reported
Contractor Hallett Construction Company Project No. I-IG-35-4/12/103
Location From Polk Co. line to Jct. New US 30

Weather Clear Wind NE 5-8 mph Temp. 71° F.
Speed 50 mph Test Personnel Dalbey & Robinson Surface P.C.

	S.T. P.C.	D. 0-NB					S.T.	D. 0-SB				
EMP	13.87					EMP	24.17					
BMP	3.95					BMP	14.20					
Length	9.92					Length	9.97					
1	4031	4031				1	4075	4075				
2	1794	3588				2	1740	3480				
3	412	1236				3	403	1209				
4	91	364				4	132	528				
5	25	125				5	60	300				
6	6	36				6	27	162				
7	1	7				7	12	84				
8	—	—				8	4	32				
9	—	—				9	1	9				
10	—	—				10	—	—				
Sum		9387				Sum		9879				
Sum/L		946				Sum/L		990				
LPV		4.65				LPV		4.60				

C.S.	S.T.	D.	C.S.	S.T.	D.
End			End		
Start			Start		
Length			Length		
Deduct			Deduct		
Length			Length		
1			1		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
10			10		
Sum			Sum		
Sum/L			Sum/L		
RMRV			RMRV		

Notes

S.T = Surface Type D. = Direction

Test Method No. Iowa 1002-B
March 1976

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION
OFFICE OF MATERIALS

Road Meter
County
J. McCaskey
V.R. Snyder (2)

1976 Present Serviceability Index Summary for Jones County (53)

Date Reported 3-16-76 Lab. No. LV6-44 to 57

Lab. No. LV-	Beginning Milepost	Ending Milepost	Road No.	Length (Miles)	Surface Type	Dir. & Lane	Longitudinal Profile Value of March 1976	Winter 75-76 Ded. for Cracking Patching	Present Serviceability Index
44	20.77	22.24	US 151	1.47	AC	EB	3.70	.05	3.65
						WB	3.70	.05	3.65
45	22.24	27.34	US 151	5.10	AC	EB	3.65	.10	3.55
						WB	3.65	.10	3.55
46	27.34	37.61	US 151	(5.58)	AC	EB	3.55	.05	3.50
						WB	3.60	.05	3.55
				(4.26)	PC	EB	3.30	.15	3.15
						WB	3.50	.15	3.35
47	38.69	48.07	US 151	(6.68)	AC	EB	3.55	.05	3.50
						WB	3.55	.05	3.50
				(2.52)	PC	EB	3.35	.10	3.25
						WB	3.25	.10	3.15
48	0.00	21.22	IA 64	(14.47)	AC	EB	3.15	.00	3.15
						WB	3.20	.00	3.20
				(5.16)	PC	EB	3.25	.70	2.55
						WB	3.25	.70	2.55
49	115.78	119.25	IA 1	3.47	AC	NB	3.05	.35	2.70
						SB	3.10	.35	2.75
50	39.10	42.44	IA 38	3.34	AC	NB	4.00	.00	4.00
						SB	3.95	.00	3.95
51	43.45	47.81	IA 38	4.36	AC	NB	3.55	.10	3.45
						SB	3.50	.10	3.40
52	50.01	53.39	IA 38	3.38	AC	NB	3.55	.00	3.55
						SB	3.55	.00	3.55
53	53.39	63.50	IA 38	10.11	AC	NB	4.00	.00	4.00
						SB	4.00	.00	4.00
54	65.11	68.41	IA 38	3.30	PC	NB	4.05	.00	4.05
						SB	4.05	.00	4.05
55	43.16	53.42	IA 136	10.26	AC	NB	3.85	.00	3.85
						SB	3.85	.00	3.85
56	54.79	58.39	IA 136	3.60	AC	NB	3.75	.05	3.70
						SB	3.80	.05	3.75
57	58.39	72.04	IA 136	13.65	AC	NB	3.90	.00	3.90
						SB	3.95	.00	3.95

Deductions for cracking and patching were calculated on a 2 lane roadway basis.

(Length) indicates tested length on an AC/PC section.

IOWA DEPARTMENT OF TRANSPORTATION

HIGHWAY DIVISION

OFFICE OF MATERIALS

LPV REPORT

Road No. I-35 County Story [illegible] IV-9-522

Year Built 1965 Date Tested 7-29-69 Date Reported 8-15-69

Contractor Hallett Construction Company Project No. I-IG-35-4/12/103

Project Length (Miles) 10.03 Surface Type PC

Location From Polk County line north to Junction New US 30

Weather Clear Wind NE 5-8 mph Temperature 71°

Test Personnel Dalbey and Robinson

	N Outside Bound Lane	S Outside Bound Lane
Length Tested	9.97	10.02
Longitudinal Profile Value	4.05	4.00
Average Longitudinal Profile Value		4.05
Deducation for Cracking, Patching and Rut Depth		0.05
Present Serviceability Index		4.00

Test Method No. Iowa 1003-A
February 1971

IOWA STATE HIGHWAY COMMISSION

Materials Department

METHOD OF DETERMINATION OF LONGITUDINAL PROFILE VALUE BY MEANS OF THE CHLOE PROFILOMETER

Scope

This method is used to determine the Longitudinal Profile Value (LPV) of pavement by the CHLOE Profilometer. The test is conducted at 5 mph, while obtaining the summation of a value $Y_{(i)}$ which can be related to the slope of the pavement and that of the square of $Y_{(i)}$, where $i = 1,2,3 \cdots N$, and N is the total number of points at 6-inch intervals. The values of N, Yi, and Yi^2, are used to determine the CHLOE Slope Variance (CSV), Road Test System Slope Variance (SV), and the Longitudinal Profile Value (LPV).

Procedure

A. Apparatus

1. CHLOE Profilometer

   a. Electronic Computer Indicator (Fig. 1).

   b. CHLOE trailer section (Fig. 2).

2. Towing and transporting vehicle.

3. Safety support vehicles as needed to insure safe operation.

B. Test Record Form

Use work sheet "LPV for PC or AC Pavement" for recording field measurements.

C. General Procedure

1. Calibration Procedure

   a. Attach the CHLOE trailer section to the towing vehicle.

   b. The roller contact, switch plate, and electronic computer indicator should be checked before beginning the road test. Anytime the data appears to be in error a check should be made and if an error is verified the malfunction should be corrected. The procedure for checking is as follows: First turn the electric eye switch at the rear of the trailer section from the road test to the manual position, then with the slope wheels up, the upright arm of the slope wheels is moved forward until the roller contact goes off the switch plate. While turning the calibrating crank, slowly move the upright arm to the rear until the roller contact impinges on the first switch segment. Hold this position and set the electronic computer indicator to zero, then turn the calibrating crank slowly until N = 10. Check to see if the quantities indicated ($\Sigma Y, \Sigma Y^2$) are correct. (Table I gives the values that should be obtained for each segment). If correct, reset the electronic computer indicator to zero, move the upright arm rearward until the number two switch segment is contacted and follow the same procedure used for the first switch segment. Continue this procedure until all 29 switch segments have been checked.

   c. Check to see if the pressure in the CHLOE trailer tires is 45 $\pm$ 0.5 psi.

   d. The position of the trailer hitch should be such that a slope mean ($\Sigma Y \div N$) between 14 and 15 is obtained. To check this, lower the slope wheels, set the electric eye switch to the road test position, and zero the electronic computer indicator. Pull the CHLOE Profilometer ahead until N = 100. The ΣY value should be between 1400 and 1500. If it is not, the trailer tongue should be raised or lowered by turning the crank at the front of the trailer section. Turning the crank counterclockwise lowers the ΣY value and turning it clockwise raises the ΣY value. Repeat the procedure if necessary.

   e. The downward force of the CHLOE slope wheels should be between 150 and 160 lbs. To check this a bathroom scale and two wooden blocks of the same thickness as the scale are needed. Pull the CHLOE carriage wheels onto the wooden blocks, then place the scale under the slope wheels and lower them. If the scale does not read between 150 and 160 lbs., adjustment can be made by turning the 3/16" knurled screw located at the bottom of the connector box fastened to the lift motor. Turning this screw clockwise will decrease the force and turning it counterclockwise will increase the force.

f. For more detailed instructions on the operation of the CHLOE Profilometer see CHLOE Profilometer Operating and Servicing Instructions.

2. Testing Procedure

a. Set the electric eye to "road test" and lower the slope wheels.

b. Set the electronic computer indicator to a zero reading.

c. Turn the counter switch on when the slope wheels reach the beginning of a test section and turn it off at the end of the section.

d. When running a test section, the speed of the towing vehicle should be about 5 mph.

e. Record the values of N, ΣY, and ΣY^2.

f. Compute the LPV as described in "Calculations".

D. Calculations (See "Typical Calculation Example.)

1. Enter the values of N, ΣY, and ΣY^2 on lines 6, 7 and 8 respectively.

2. Divide ΣY by N to an accuracy of one ten-thousandth (0.0001) and enter on line 9.

3. Square this number and record the result to the nearest thousandth (0.001) on line 11.

4. Divide ΣY^2 by N, round the answer to the nearest thousandth, and record it on line 10.

5. Subtract line 11 from line 10 and enter the result on line 12.

6. Multiply line 12 by 8.46 to obtain the CHLOE Slope Variance (line 13).

7. Subtract 2.00 from the CHLOE Slope Variance and place the result on line 14.

8. Find the log of line 14, record it on line 15.

9. Multiply line 15 by 1.80 if the surface type is PC or 1.91 if AC, and record this result on line 17.

10. On line 16 enter 5.41 if the surface type is PC or 5.03 if the surface type is AC.

11. Subtract line 17 from line 16 to obtain the Longitudinal Profile Value (LPV) of the test section.

Precautions

A. The voltage supply to the CHLOE Profilometer from the batteries must not be less than 11.5 V.

B. The operator must watch the electronic computer indicator closely to insure that it is working properly.

Reporting of Results

Enter state, county, route no., location, project, weather, date and test personnel in the appropriate places on the work sheet.

The LPV determined by the CHLOE Profilometer may be used along with other factors to calculate a Present Serviceability Index as described in "Method of Determination of Present Serviceability Index". (Test Method No. Iowa 1004.)

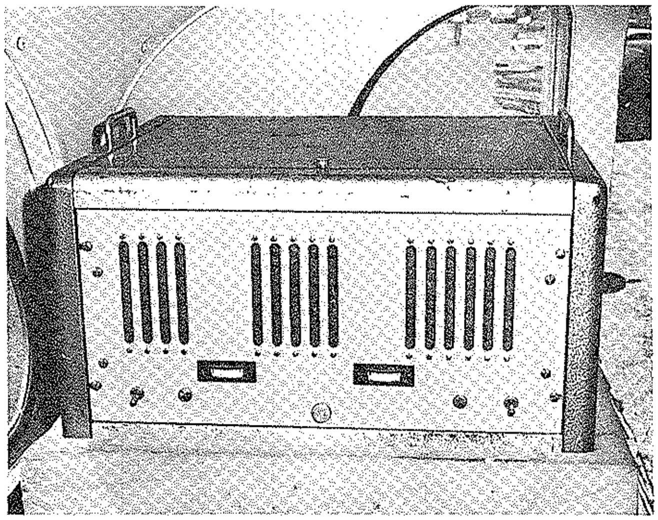

Fig. 1
Electronic Computer Indicator

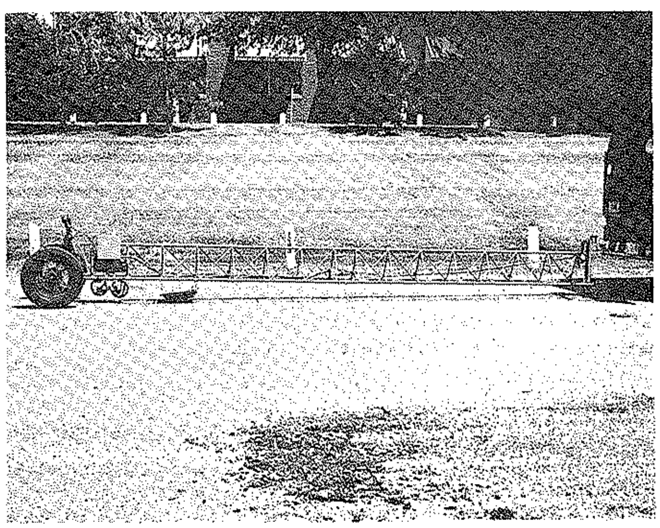

Fig. 2
CHLOE Trailer Section

TABLE I

Switch Segment	N=10 Y	Y^2
1	10	10
2	20	40
3	30	90
4	40	160
5	50	250
6	60	360
7	70	490
8	80	640
9	90	810
10	100	1,000
11	110	1,210
12	120	1,440
13	130	1,690
14	140	1,960
15	150	2,250
16	160	2,560
17	170	2,890
18	180	3,240
19	190	3,610
20	200	4,000
21	210	4,410
22	220	4,840
23	230	5,290
24	240	5,760
25	250	6,250
26	260	6,760
27	270	7,290
28	280	7,840
29	290	8,410

TYPICAL CALCULATION EXAMPLE
LPV for PC or AC Pavement

State Iowa — Location E. of Ames — Date 4-16-70

County Story — Project ______ — Test Personnel ______

Route No. 13th Street — Weather ______

1	Section No.	10									
2	Location	1648-1673									
3	Surface Type	PC									
4	Direction	EB									
5	Wheelpath	O									
6	No. of readings (N)	4951									
7	ΣY	71733									
8	ΣY^2	1044724									
9	$(\Sigma Y/N)$	14.4886									
10	$\Sigma Y^2/N$	211.013									
11	$(\Sigma Y/N)^2$	209.920									
12	(line 10 - line 11)	1.093									
13	CSV = (line 12) x 8.46	9.247									
14	(1 + SV) = (line 13 - 2)*	7.247									
15	Log (1 + SV) = Log (line 14)	0.8596									
16	Enter 5.41 for PC, or 5.03 for AC	5.41									
17	If PC 1.80 x line 15 If AC 1.91 x line 15	1.55									
18	LPV = (line 16 - line 17)	3.86									

* SV = CSV - 3

LPV(PC) = 5.41 - 1.80 Log (1+SV)

LPV(AC) = 5.03 - 1.91 Log (1+SV)

Test Method No. Iowa 1004-C
December 1981

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION

Office of Materials

METHOD OF DETERMINATION OF PRESENT SERVICEABILITY INDEX

General Scope

The Present Serviceability Index (PSI) was developed by the AASHO Road Test as an objective means of evaluating the ability of a pavement to serve traffic. The Present Serviceability Index is primarily a function of longitudinal profile with some influence from cracking, patching and rut depth.

The AASHO rating scale ranges from 0 to 5 with adjective designations of:

Very Poor	0 - 1
Poor	1 - 2
Fair	2 - 3
Good	3 - 4
Very Good	4 - 5

The Bureau of Public Roads has a similar scale with the following designations which are more realistic in the evaluation of new pavements:

PSI	Rating
Above 4.5	Outstanding
4.5 - 4.1	Excellent
4.1 - 3.7	Good
3.7 - 3.3	Fair
Below 3.3	Poor

The test is conducted in two parts: (1) Determination of the Longitudinal Profile Value (LPV), (2) Determination of Deduction for Cracking, Patching and Rut Depth.

Part I. Determination of the Longitudinal Profile Value

Scope:

The Iowa DOT uses three methods for determination of the longitudinal profile value:

1. CHLOE Profilometer
2. BPR Type Road Roughometer
3. IJK Type Road Meter

Test Procedure:

1. The determination of longitudinal profile value by the CHLOE Profilometer is described in Test Method No. Iowa 1003-A.

2. The determination of road roughness by the BPR Type Roughometer is described in Test Method No. Iowa 1001-A. The inches per mile as described therein is then used in conjunction with the most current correlation of road roughness (inches/mile) vs. longitudinal profile value (LPV) determined by the CHLOE Profilometer to obtain a longitudinal profile value.

3. The determination of the road meter roughness value, which is the same as the Longitudinal Profile Value, by the IJK Type Road Meter, is described in Test Method No. Iowa 1002-B.

Part II. Determination of Deduction for Cracking, Patching and Rut Depth

Scope:

The purpose of this portion of the test is to determine the value of the Present Serviceability Index lost due to physical deterioration of the roadway.

The evaluation is conducted according to general procedure established by the AASHO Road Test and described in detail in the "Highway Research Board Special Report 61E

Test Procedure -- Flexible Pavement:

The equation for Present Serviceability Index of flexible pavement is:

$$PSI = LPV - .01 \sqrt{C+P} - 1.38\ \overline{RD}^2$$

where;

PSI = Present Serviceability Index

LPV = Longitudinal Profile Value

C+P = Measures of cracking and patching of the pavement

$\overline{RD}$ = A measure of rutting in the wheel paths

Cracking, C, is defined as the square feet per 1000 square feet of pavement surface exhibiting alligator or fatigue cracking. This type of cracking is defined as load related cracking which has progressed to the state where cracks have connected together to form a grid like pattern resembling chicken wire or the skin of an alligator. This type of distress can advance to the point where the individual pieces become loosened.

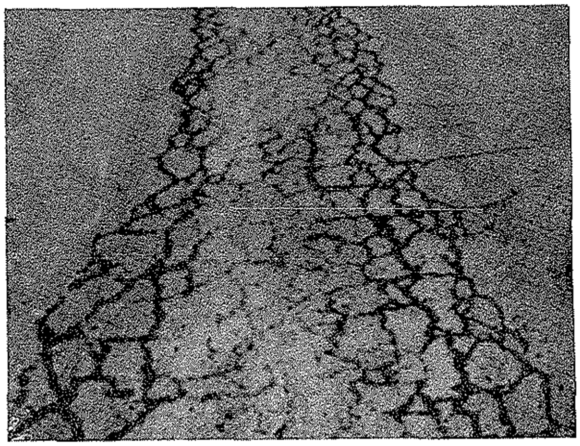

Figure 1.

Alligator cracking

Patching, P, is the repair of the pavement surface by skin (i.e. widening joint strip seal) or full depth patching. It is measured in square feet per 1000 square feet of pavement surface.

Rut depth, $\overline{RD}$, is defined as the mean depth of rutting, in inches, in the wheel paths under a 4-ft straightedge.

Cracking, L, is defined as the number of longitudinal (parallel to traffic flow) cracks which excede 100 feet in length and 1) are open to a width of 1/4" over half their length or 2) have been sealed. If these cracks are observed to occur less than 3 feet from one another, the condition described under C should be looked for and if present reported instead of reporting the distress as longitudinal cracking.

Cracking, T, is defined as the number of transverse (right angles to traffic direction) cracks that are open to a width of 1/4" over half their length or have been sealed. Random or diagonal cracks are ignored.

Faulting, F, is defined as the mean vertical displacement, in inches, measured with a 4-ft. straightedge.

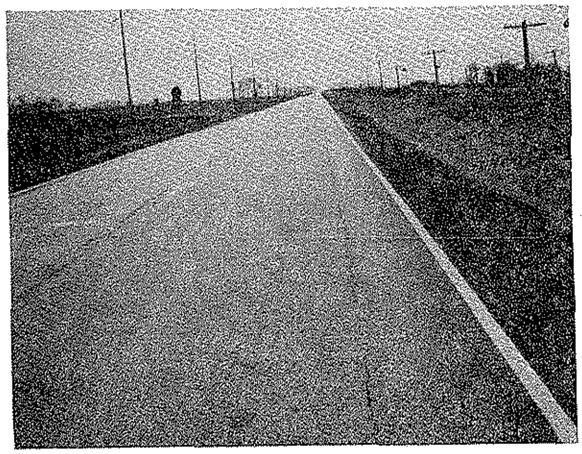

Figure 2.

Longitudinal Cracks

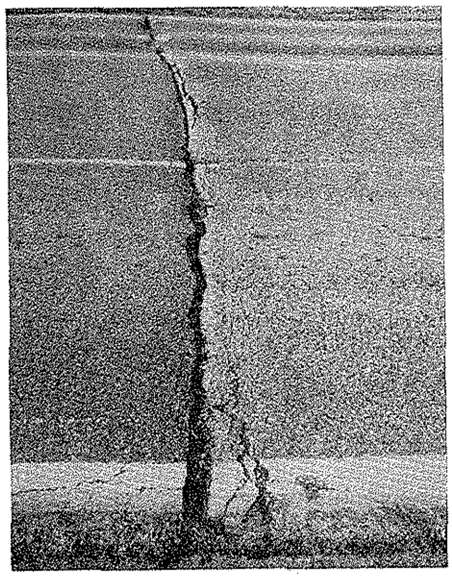

Figure 3.

Transverse Cracks and Faulting

Test Procedure -- Rigid Pavement:

The equation for Present Serviceability Index of rigid pavement is:

$$PSI = LPV - .09\sqrt{C+P}$$

where;

PSI = Present Serviceability Index

LPV = Longitudinal Profile Value

C+P = Measures of cracking and patching of the pavement

Cracking, C, is defined as the lineal feet of cracking per 1000 square feet of pavement surface. Only those cracks which are open to a width of 1/4" or more over half their length or which have been sealed are to be included.

Patching, P, is the repair of the pavement surface by skin or full depth patching. It is measured in square feet per 1000 square feet of pavement surface.

Rut depth, $\overline{RD}$, is defined as the mean depth of rutting, in inches, in the wheel paths under a 4-ft. straightedge.

Faulting, F, is defined as the mean vertical displacement, in inches, measured with a 4-ft. straightedge.

D-cracking, D, refers to a characteristic pattern than can develop in portland cement concrete. Initially, the occurrence of D-cracking _may_ be preceded and accompanied by staining of the pavement surface near joints and cracks. However, _not all stained joints and cracks develop D-cracking_. D-cracked concrete will first exhibit fine parallel cracks adjacent to the transverse and longitudinal joints at the interior corners. The D-cracks will bend around the corner in a concave or hourglass pattern. As the D-cracking progresses, the entire length of the transverse, longitudinal and random cracks will be affected. The cracked pieces may become loose and dislodged under the action of traffic. The occurrence of D-cracking in the check sections will be rated on a point scale as described in the Test Procedure section.

Figure 4.

D-cracking - Initial stages

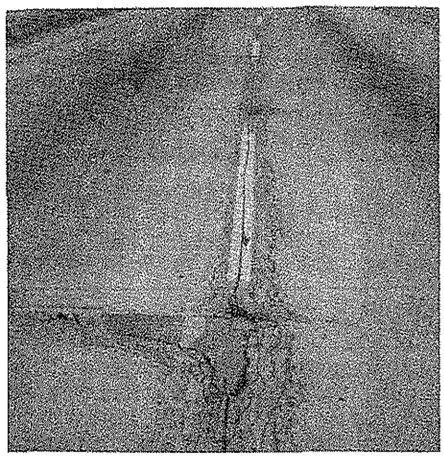

Figure 5.

D-cracking - All joints affected

Procedure

A. Apparatus

1. A passenger vehicle with an accurate odometer.
2. A four foot long rut/fault gauge.
3. Mechanical counters.
4. A 50-foot tape.
5. Safety equipment -- hard hats, safety vests, survey signs.

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B. Test Record Forms

1. Crack and Patch Survey worksheet (A.C. or P.C.C.).

2. Crack and Patch Calculation and Summary Sheet.

3. Present Serviceability Index Summary (Form 915).

C. Test Procedure

The control sections are as described in the "Control Sections by Mileposts" booklet. For control sections of 0-5.00 miles in length, one representative 1/2 mile test section will be evaluated. For 5.01-10.00 miles, two 1/2 mile test sections are used. Three 1/2 mile sections are used for any control section greater than 10.0 miles.

After determining a location for the representative 1/2 mile test section or sections, the county, highway number, beginning and ending control section milepost, pavement width, beginning and ending milepost of the 1/2 mile test section being surveyed, date of survey and names of those doing the survey shall be recorded on the worksheet.

Flexible

The procedure for evaluation of flexible pavement is to drive on the shoulder, if possible, and estimate the area of each instance of alligator cracking and patching recording them individually on the worksheet.

The rut depth is measured in the outside and inside wheeltrack in both lanes at 0.05 mile intervals and recorded (10 sets of readings per test section).

While driving the first and last 0.05 mile portion of the test section the number of longitudinal and transverse cracks meeting the previously described criteria will be counted and recorded. Transverse cracks extending across only one lane will be counted as "half cracks" and recorded as such.

While driving the first and last 0.05 mile portions, the occurrence of faulted cracks will be looked for and the worst instance in each portion will be measured. These measurements will be taken one foot in from the pavement edges at the two cracks selected and the data recorded.

Rigid

The procedure for rigid pavement is to drive on the shoulder, if possible, and count all cracks meeting the previously described criteria. Cracks extending across only one lane are recorded as "half cracks" and summed to full cracks during the data summary phase. Longitudinal, diagonal and random cracks are accounted for by estimating how many times they would extend across the roadway and recording that number.

The area of each patch is estimated and recorded individually on the worksheet.

The rut depth is measured in the outside and inside wheeltracks of both lanes. One set of measurements will be taken at the beginning of the 1/2 mile test section and one set at the end.

Faulting is measured one foot in from each pavement edge at 0.05 mile intervals and recorded (10 sets of readings per check section).

The D-crack Occurrence Factor (DOF) in the test section will be evaluated and assigned a numerical rating based on the following description.

DOF Value

0 = No D-cracking noticeable

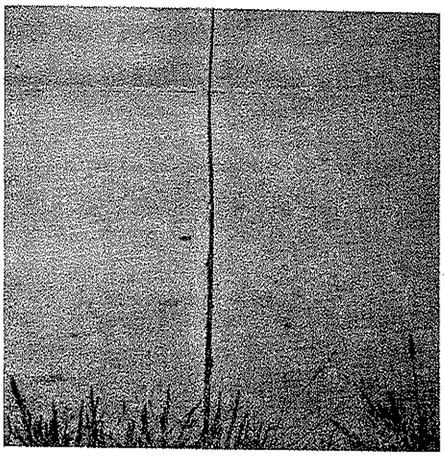
1 = D-cracking is evident at some joints especially the interior corners. Pavement is sound condition and no maintenance is required due to D-cracks.

2 = D-cracking is evident at most joints and has progressed across width of slab. Pavement is in sound condition and no maintenance is required due to D-cracking.

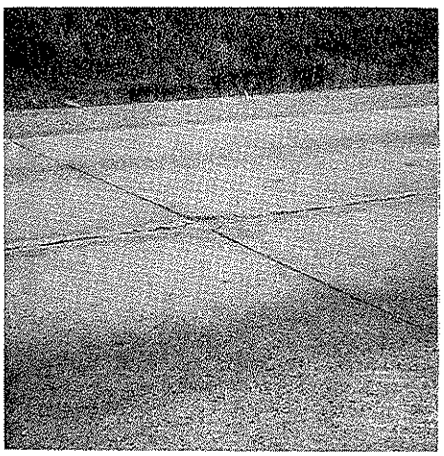
3 = D-cracking is evident at virtually all joints and random cracks. Minor raveling and spalling are occurring and traffic is causing some loosening of cracked pavement. Some minor maintenance of spalled areas is required.

4 = D-cracking very evident as in 3 above. Spalling and removal by traffic has progressed to point that regular maintenance patching is required. Effect on riding quality of pavement is now noticeable.

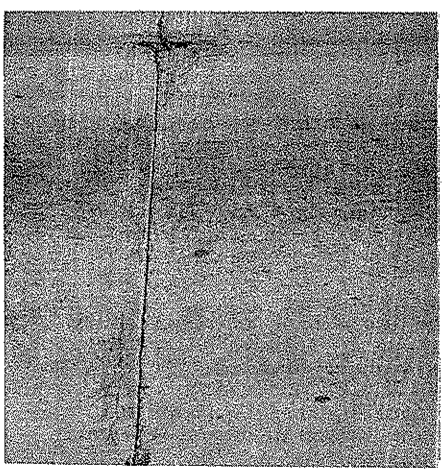
5 = D-cracking has continued to progress at sites identified in 3 above and requires regular maintenance patching. Full depth patches may be necessary. Ride quality has deteriorated to point where reduced driving speed is necessary for comfort and safety.



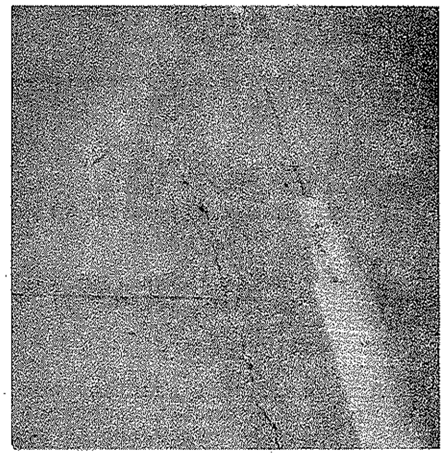
DOF = 0



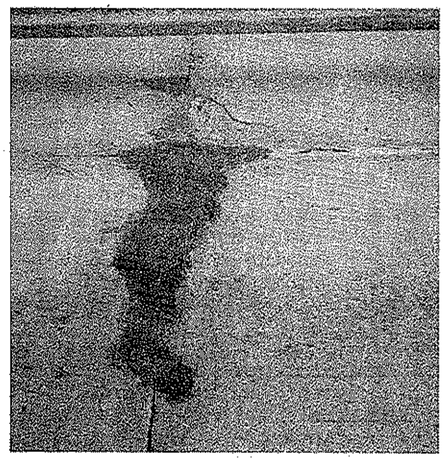
DOF = 1



DOF = 2



DOF = 3



DOF = 4

DOF = 5

Figure 6. Examples of D-crack Occurrence Factors

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D. Calculations

1. Flexible Pavement

a. The area of cracking is totaled and divided by the area of the test section in thousands of square feet to obtain C.

b. The area of patching is totaled and divided by the area of the test section in thousands of square feet to obtain P.

c. The rut depth measurements are totaled and averaged to obtain $\overline{RD}$.

D. The number of longitudinal cracks in the two areas surveyed are totaled, averaged, and reported as L.

e. The number of transverse cracks and 1/2 cracks (divided by 2) in the two areas surveyed are totaled, averaged, and reported as T.

f. The faulting measurements are totaled and averaged to obtain F.

g. Cracking (C), patching (P), and rut depth ($\overline{RD}$) as calculated above and LPV, as determined in Part I, are used in the following formula to determine the Present Serviceability Index (PSI):

$$PSI = LPV - 0.01\sqrt{C+P} - 1.38\ \overline{RD}^2$$

2. Rigid Pavement

a. The number of cracks and 1/2 cracks (divided by 2) are totaled and multiplied by the width of the roadway and divided by the area of the test section in thousands of square feet to obtain C.

b. The area of patching is totaled and divided by the area of the test section in thousands of square feet to obtain P.

c. The rut depth measurements are totaled and averaged to obtain $\overline{RD}$.

d. The faulting measurements are totaled and averaged to obtain F.

e. Cracking (C) and patching (P) as calculated above and LPV as determined in Part I are used in the following formula to determine the Present Serviceability Index (PSI):

$$PSI = LPV - .09\ \sqrt{C+P}$$

E. Reporting Results

1. Lab. Number.
2. Beginning Milepost.
3. Ending Milepost.
4. Road Number.
5. Length.
6. Surface Type.
7. Direction and Lane.
8. RMRV or LPV.
9. Deduction for cracking and patching.
10. Present Serviceability Index.

APPENDIX B: DESCRIPTION OF PASCO SYSTEMS OPERATION

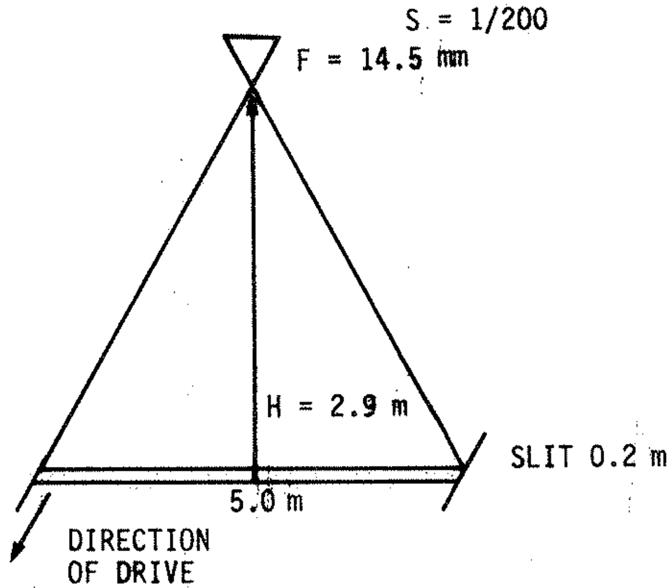


Fig. B.1. The ROADRECON-70.

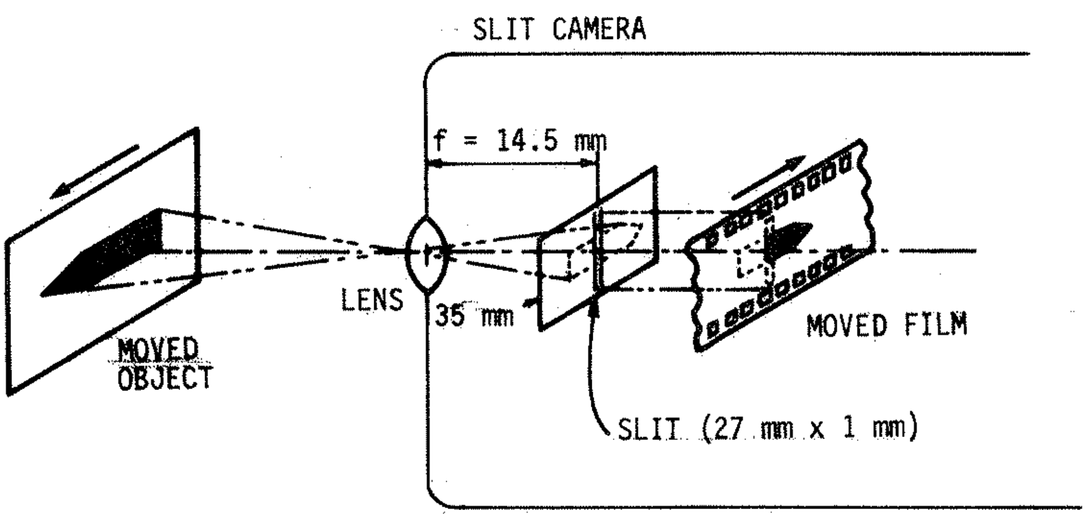


Fig. B.2. Slit camera.

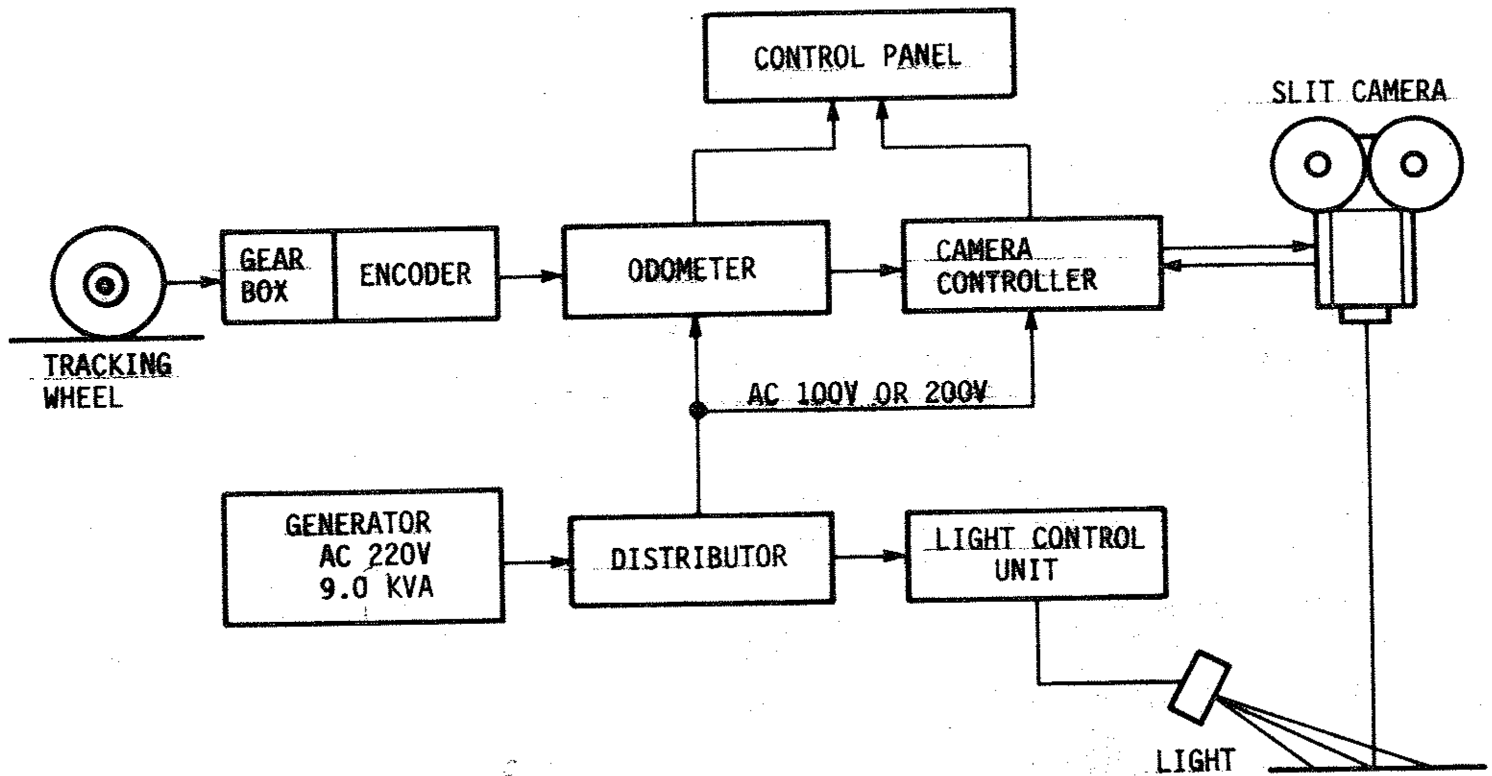
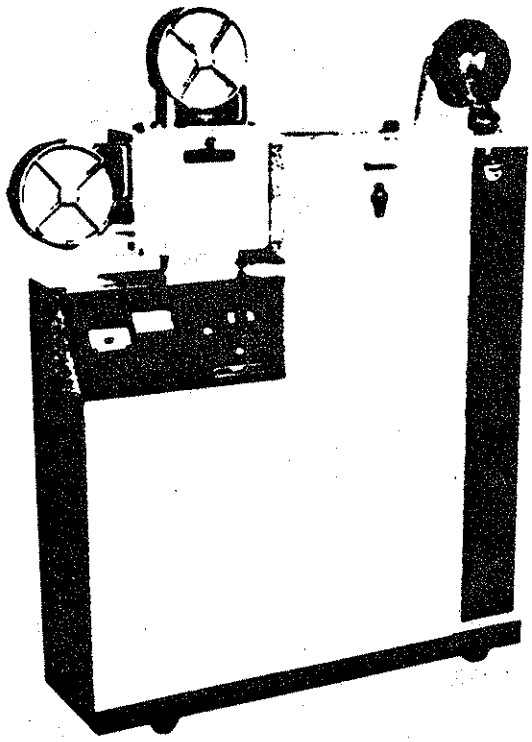
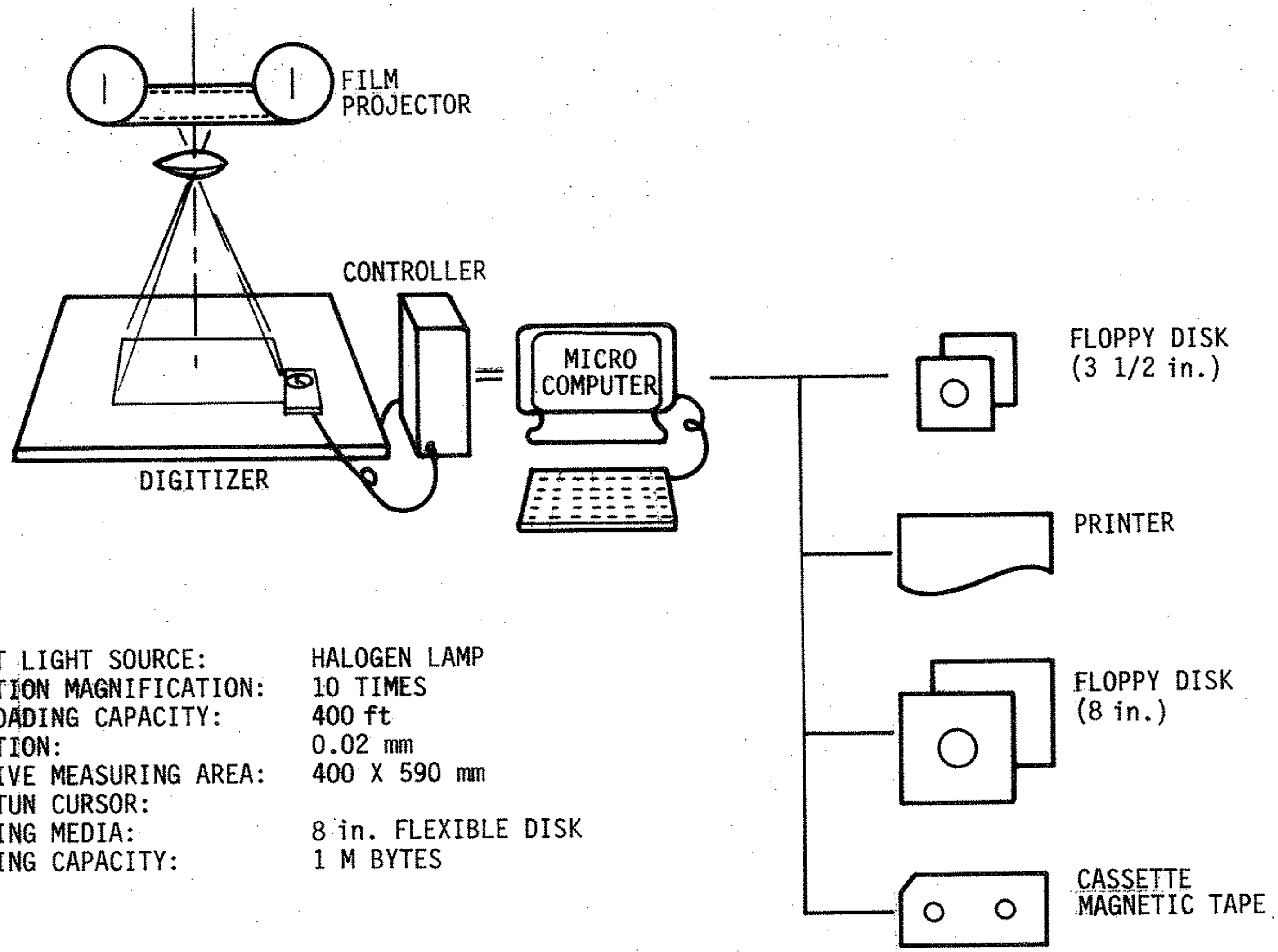


Fig. B.3. ROADRECON-70 system.



Processing speed:	0 - 30 feet/min.
Developing temperature:	15°- 40°C
Fixing temperature:	fixed at 28°C
Drying temperature:	40° - 70°C
Water consumption:	4 liters/min.(at 4° - 30°C)
Film magazine:	1,000 feet

Fig. B.4. Automatic film processor.



PROJECT LIGHT SOURCE:	HALOGEN LAMP
PROJECTION MAGNIFICATION:	10 TIMES
FILM LOADING CAPACITY:	400 ft
RESOLUTION:	0.02 mm
EFFECTIVE MEASURING AREA:	400 X 590 mm
16-BOTTUN CURSOR:	
RECORDING MEDIA:	8 in. FLEXIBLE DISK
RECORDING CAPACITY:	1 M BYTES

Fig. B.5. ROADRECON film digitizer.

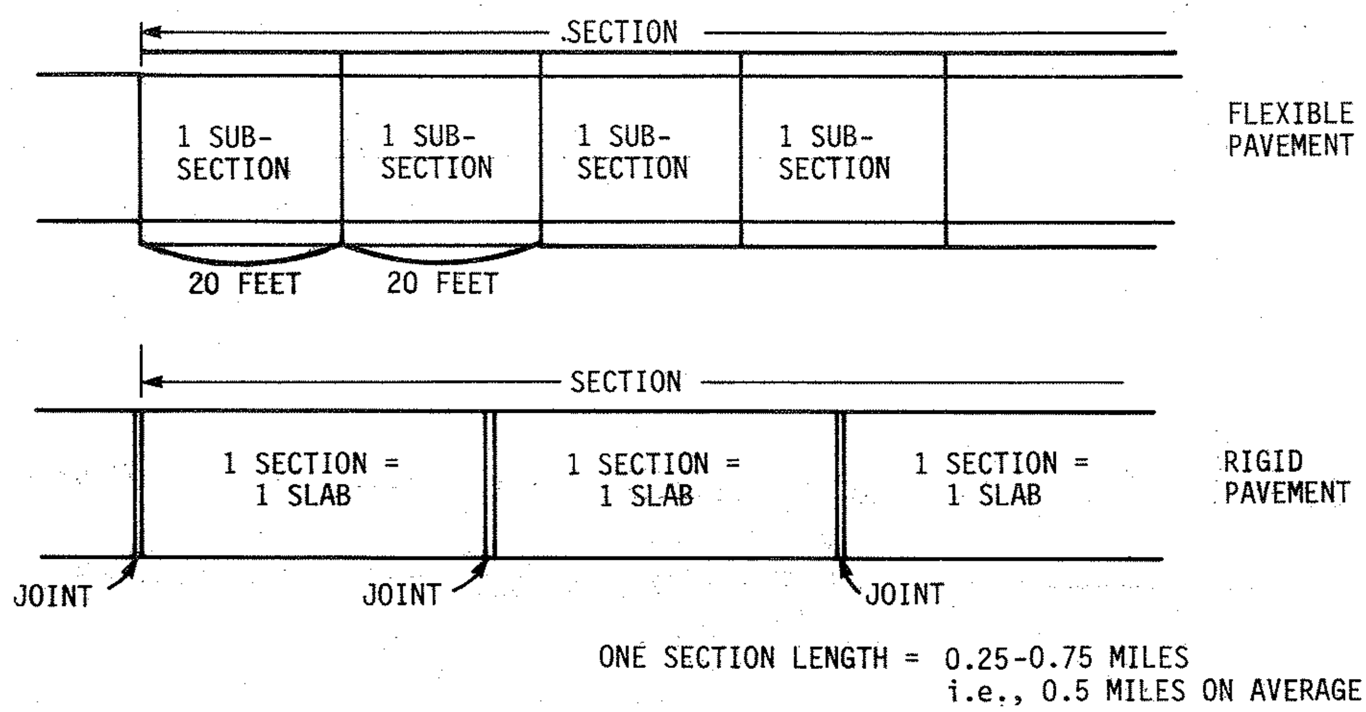


Fig. B.6. Definition of subsection.

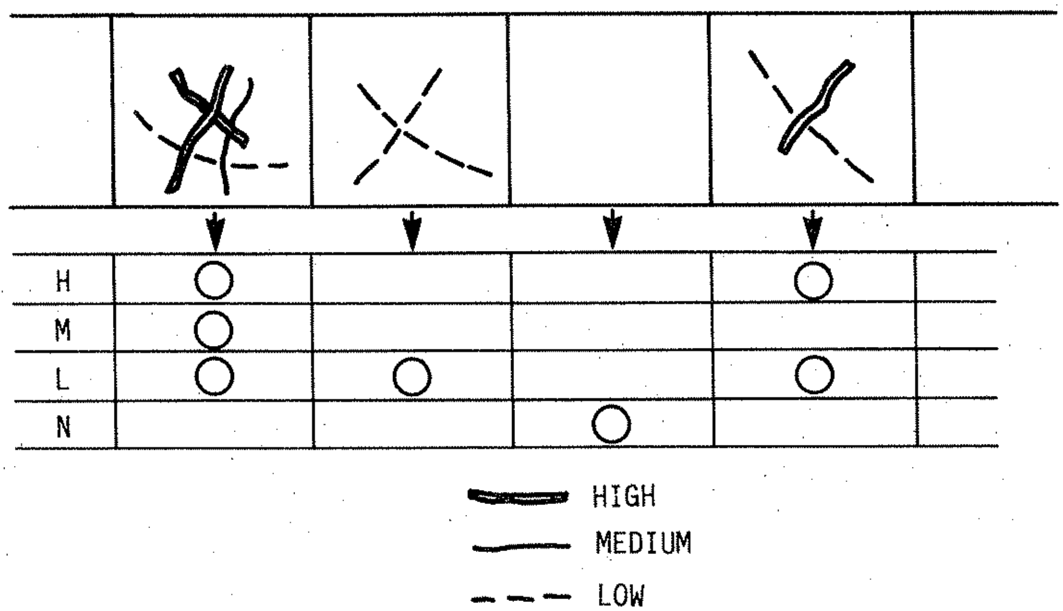


Fig. B.7. Interpretation of cracking on ROADRECON-70 film positives.

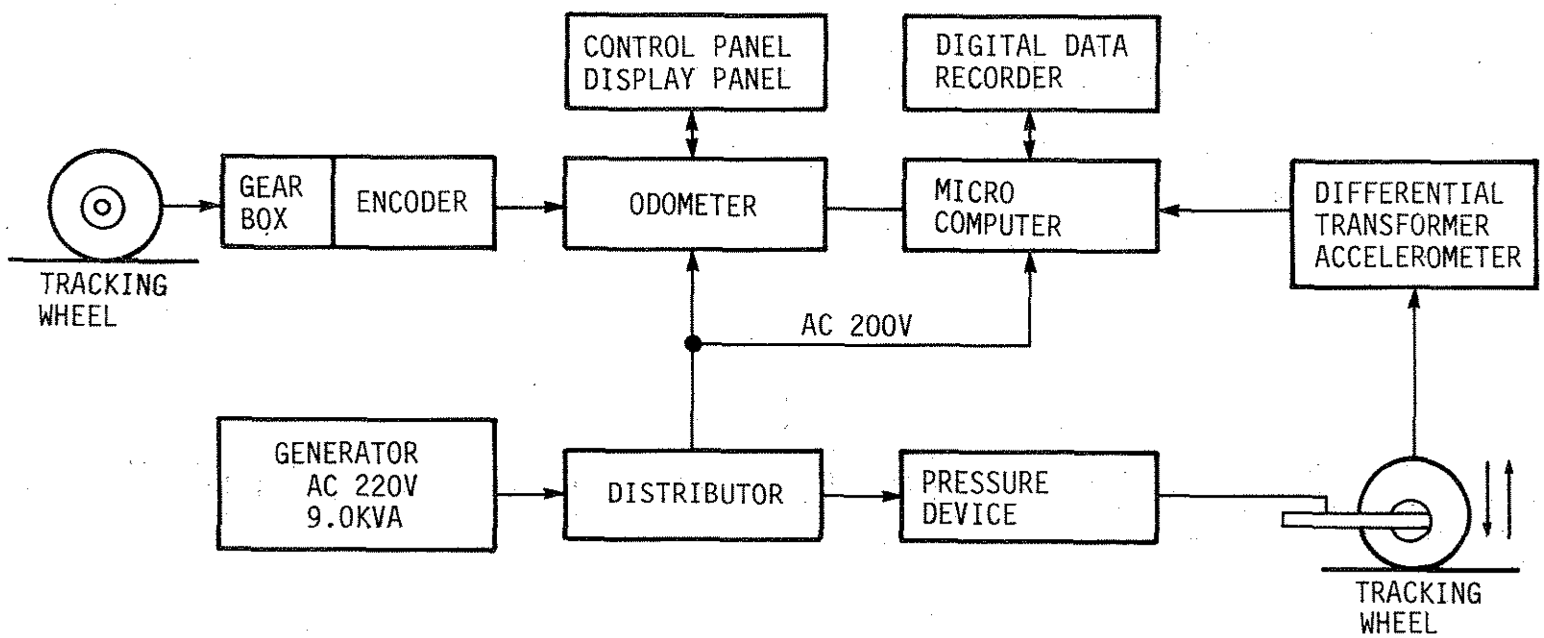


Fig. B.8. ROADRECON 77 system.

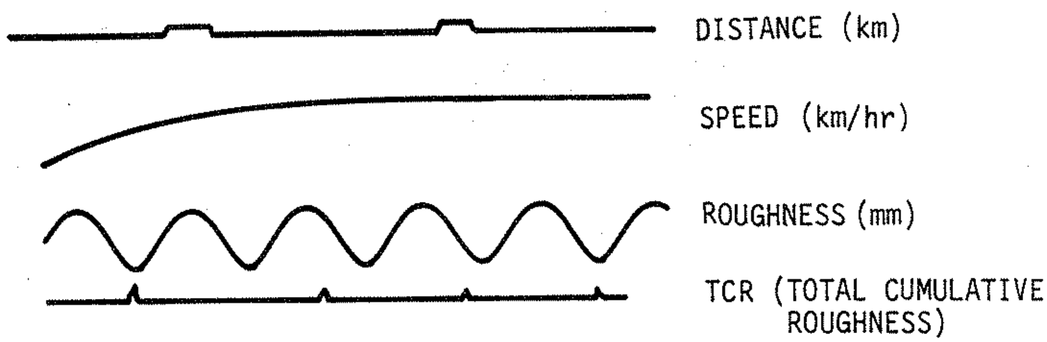


Fig. B.9. Paper chart.

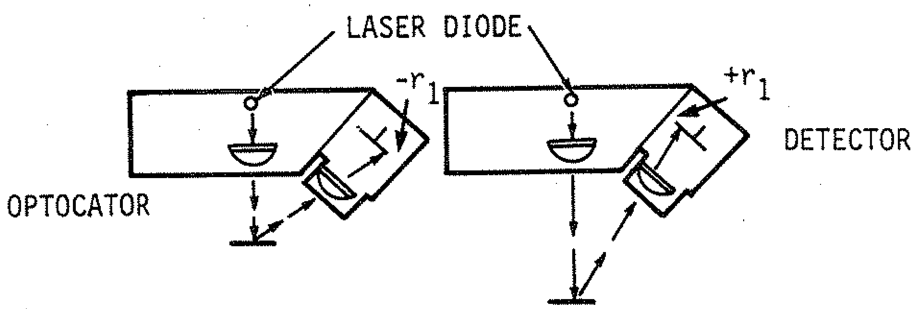


Fig. B.10. Laser reflection.

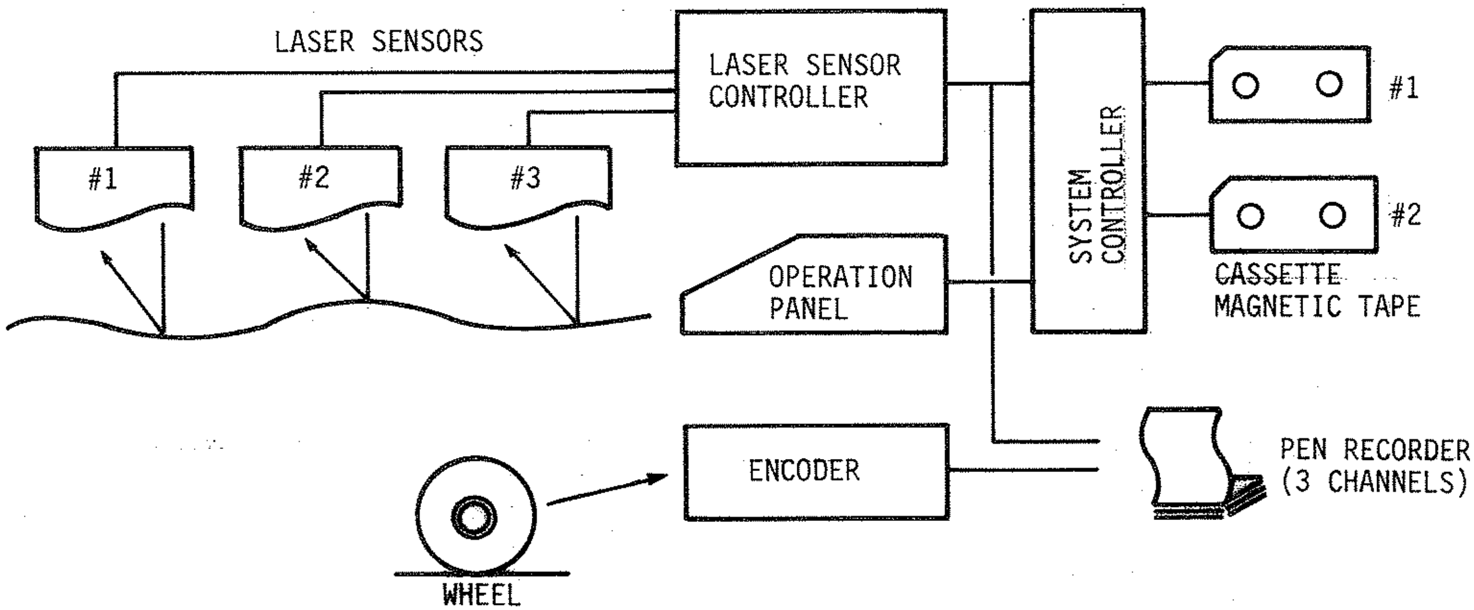


Fig. B. 11. Diagram of laser system composition. (ROADRECON-85B).

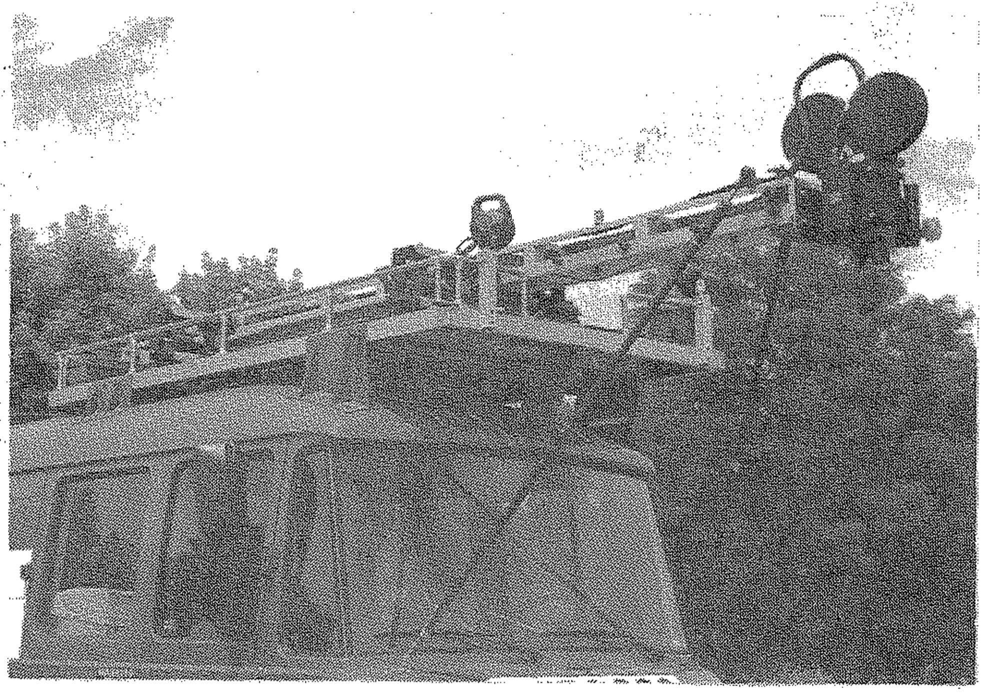


Fig. B.12. Camera mounting on PASCO vehicle.

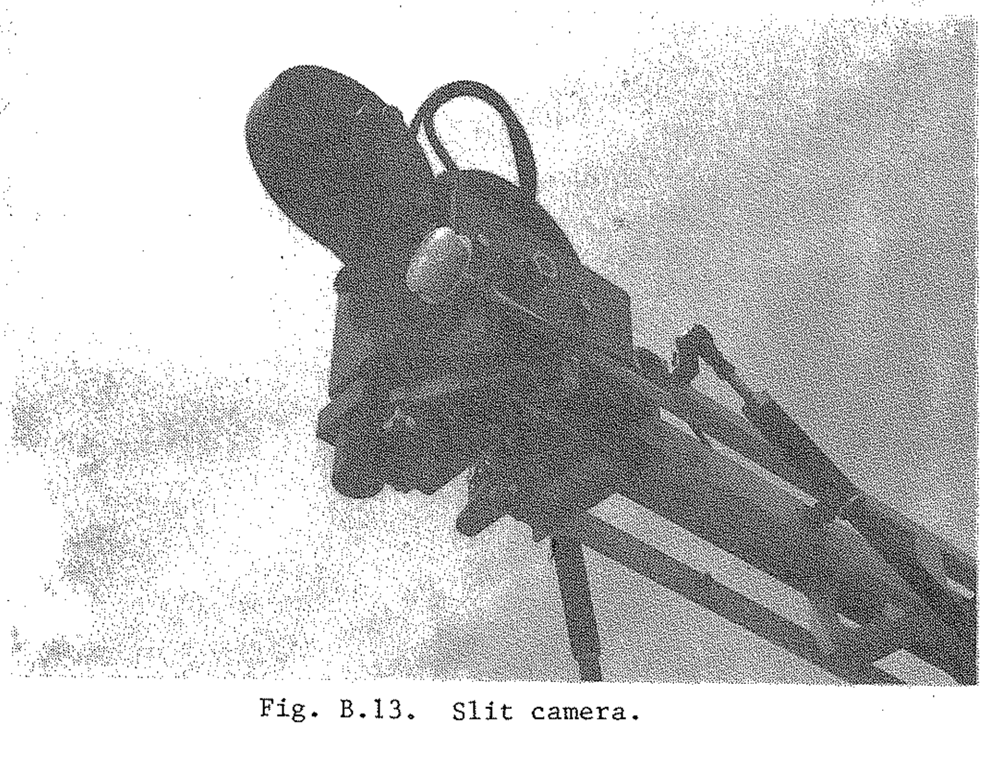


Fig. B.13. Slit camera.

Fig. B.14. Laser mounting on PASCO vehicle.

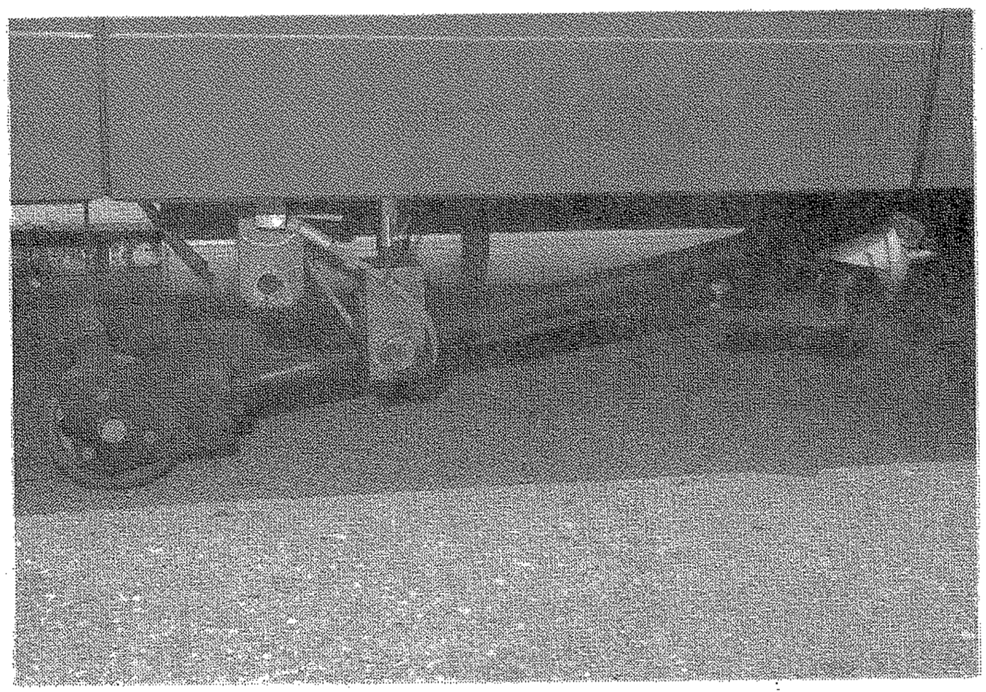


Fig. B.15. Tracking wheel mounting on PASCO vehicle.

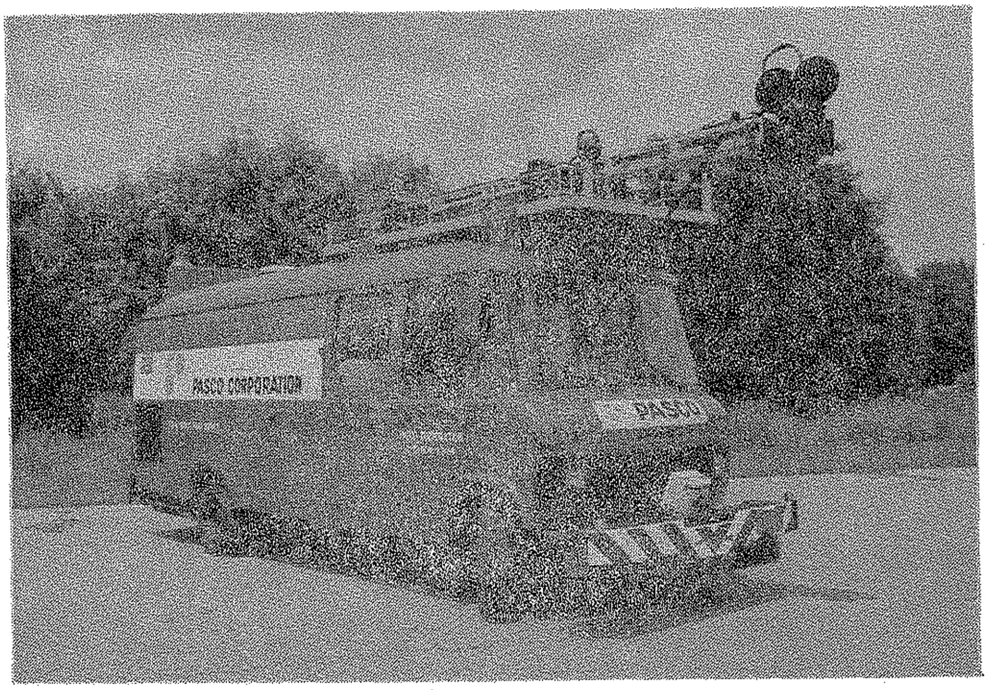


Fig. B.16. PASCO vehicle.

Fig. B.17. Hairline projection mounting on PASCO vehicle.

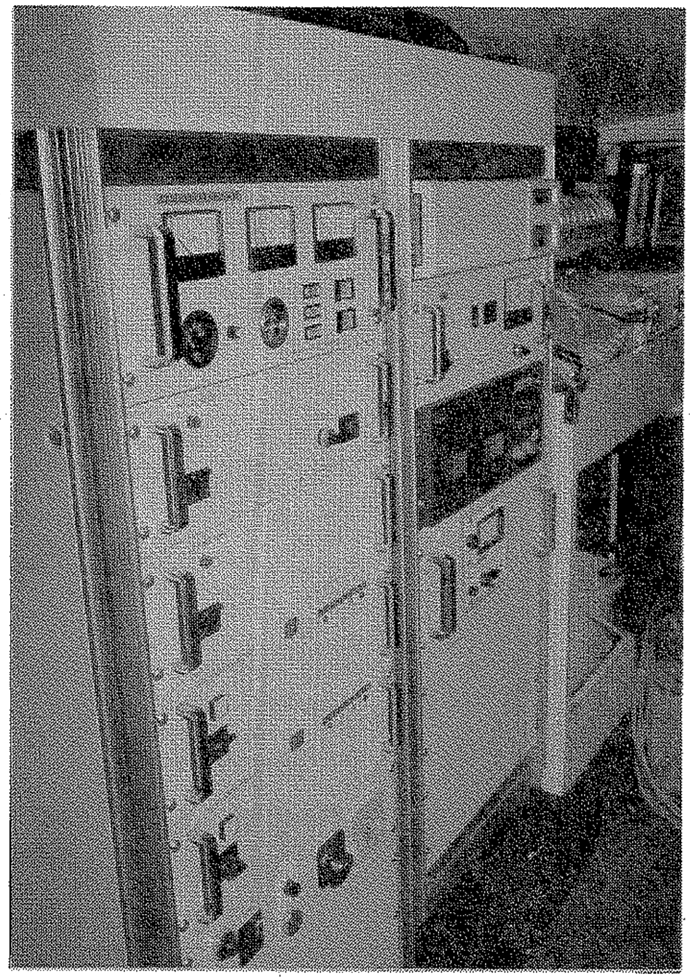


Fig. B.18. Computer on board the PASCO vehicle.

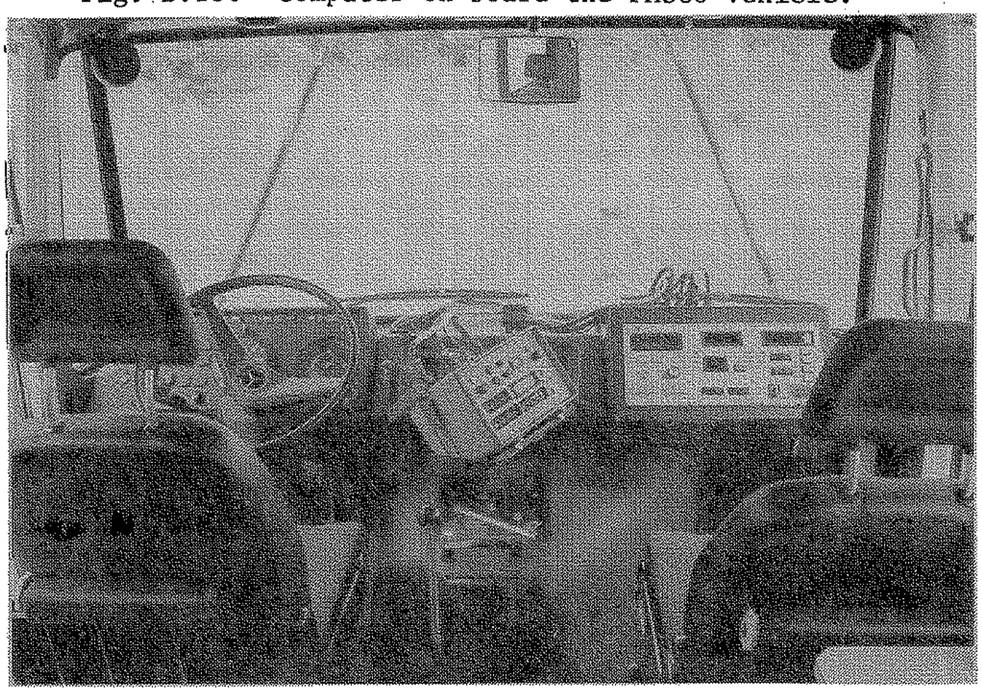


Fig. B.19. Inside view of PASCO vehicle.

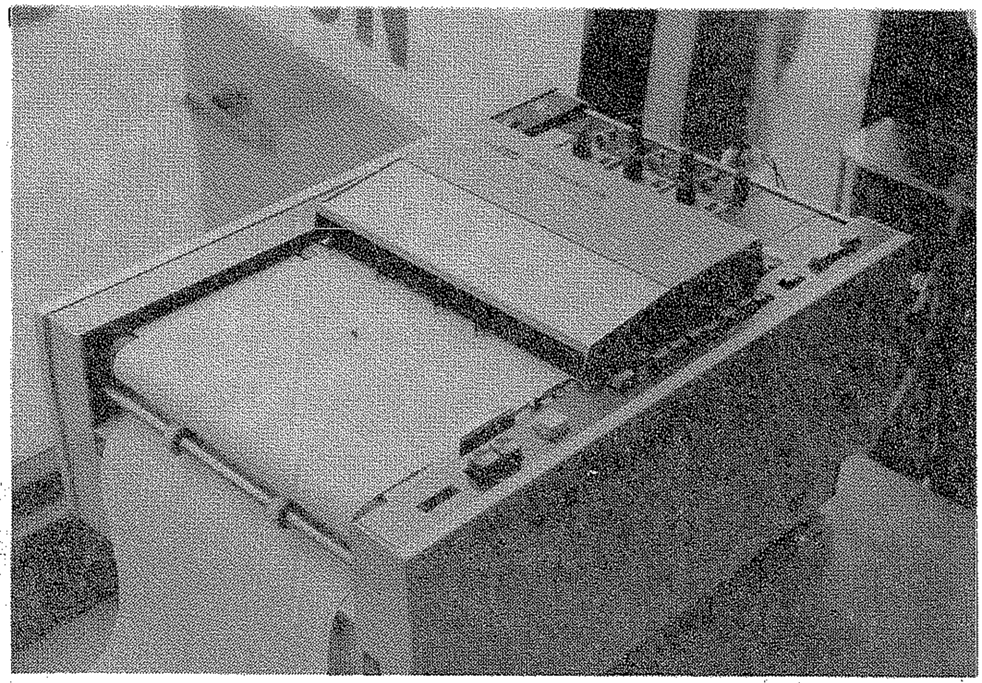


Fig. B.20. Paper chart plotter mounting on PASCO vehicle.

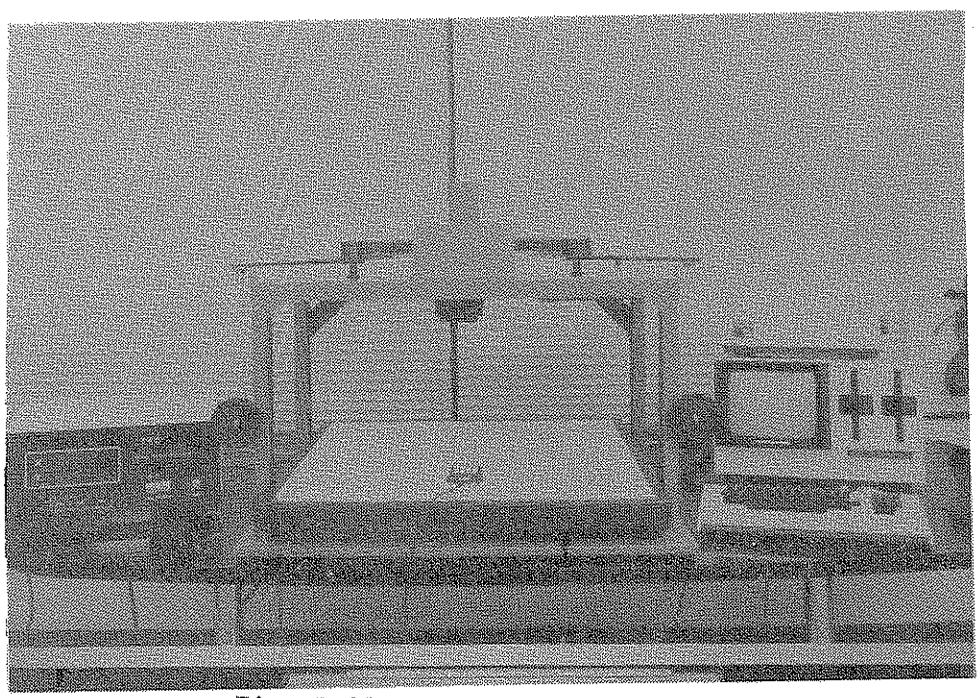


Fig. B.21. Photo analyzer.

Fig. B.22. PASCO vehicle--night operation.

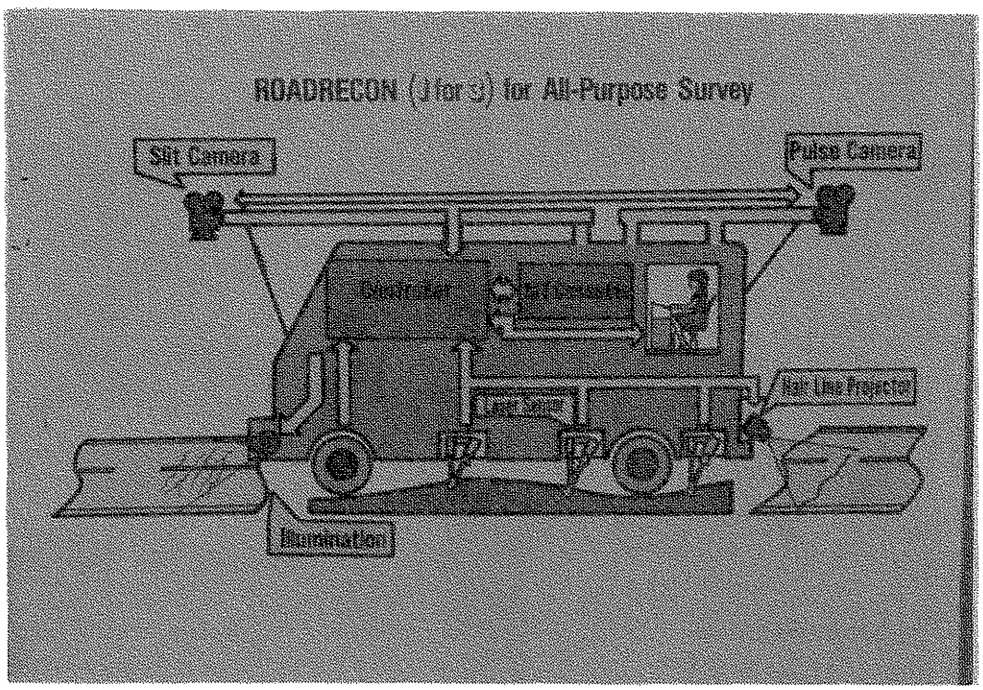


Fig. B.23. PASCO--all purpose survey system.

APPENDIX C: EVALUATION METHODS AND STATISTICAL COMPARISONS

Evaluation Methods

Both PASCO and Iowa DOT methods were used to evaluate the surface conditions of all seven sections, including some shoulders of the sections. The cracking, patching, roughness, and the total evaluation were compared by using a simple linear regression model. Supposing that X_i is the observation by the PASCO method and Y_i is the corresponding value by the Iowa DOT method, then ideally

$$Y_i = m X_i + C$$

where m (gradient of the straight line) and c (intercept of the straight line) are constant. Now if we have n such observations, we have

$$\begin{pmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_n \end{pmatrix} = \begin{pmatrix} x_1 & 1 \\ x_2 & 1 \\ \cdot & \\ \cdot & \\ x_n & 1 \end{pmatrix} \begin{pmatrix} m \\ c \end{pmatrix}$$

$$\therefore L = A \cdot Z$$

where

$$\text{matrix } L = \begin{pmatrix} y_i \\ y \\ y_n \end{pmatrix} ; \; A = \begin{pmatrix} x_1 \\ x_2 \\ x_n \end{pmatrix} \begin{matrix} 1 \\ 1 \\ 1 \end{matrix} ; \text{ and } Z = \begin{pmatrix} m \\ c \end{pmatrix}$$

∴ Using the least squares method we have

$$Z = \begin{pmatrix} m \\ c \end{pmatrix} = \left(A^T A\right)^{-1} (A^T L)$$

$$\begin{pmatrix} m \\ c \end{pmatrix} = \begin{pmatrix} \Sigma x^2 & \Sigma x \\ \Sigma x & n \end{pmatrix}^{-1} \begin{pmatrix} \Sigma xy \\ \Sigma y \end{pmatrix}$$

Now, if we shift x_i, such that $x'_i = x_i - \bar{x}$ where $\bar{x} = \Sigma x/n$, then

$$Y_i = m\ (x'_i + \bar{x}) + C$$

$$m\ x'_i + m\bar{x} + C = m\ x'_i + C'$$

$$\therefore \begin{pmatrix} m \\ c' \end{pmatrix} = \begin{pmatrix} \Sigma x'^2 & 0 \\ 0 & n \end{pmatrix}^{-1} \begin{pmatrix} \Sigma x'y \\ \Sigma y \end{pmatrix}$$

$$\therefore m = \frac{\Sigma x'y}{\Sigma x'^2} = \frac{\Sigma(x_i - \bar{x})y}{\Sigma \ x_i - \bar{x}^{\ 2}} = \frac{\Sigma x_i y_i - \left(\frac{\Sigma x_i}{n}\right) \Sigma y}{\Sigma x_i^{\ 2} - 2\left(\frac{\Sigma x_i}{n}\right) \Sigma x_i + \left(\frac{\Sigma x_i}{n}\right)^2}$$

$$c' = \frac{\Sigma y}{n}$$

$$\therefore c = c' - m\,\frac{\Sigma x}{m} = \left(\frac{\Sigma y}{n}\right) - m\left(\frac{\Sigma x}{n}\right)$$

The covariance between x and y observations is then given by

$$\sigma_{xy} = \frac{\Sigma(x - \bar{x})(y - \bar{y})}{\sigma_x \cdot \sigma_y}$$

where

$$\sigma_x{}^2 = \frac{\Sigma(x - \bar{x})^2}{n - 1}$$

and

$$\sigma_y{}^2 = \frac{\Sigma(y - \bar{y})^2}{n - 1}$$

$$\sigma_{xy} = r = \text{correlation between the two observations}$$

$$= \frac{\Sigma\left(\hat{y}_i - \bar{y}\right)^2}{\Sigma\left(y_i - \bar{y}\right)^2}$$

where

$$\bar{y} = \frac{\Sigma y_i}{n}$$

and

$$\hat{y}_i = \hat{m}\, x_i + \hat{c}$$

where $\hat{m}$ and $\hat{c}$ are the values obtained by the least squares method. If $r = 1$, then the two observations are correlated and are comparable; if $r = 0$ then they are not comparable. As a rule, if $r > 0.5$ one could say that both the observations should give the same result (better than 50% probability), and if $r < 0.5$ then one could conclude that both results may not give the same result. However, for statistical analysis,

$$t = \sqrt{\frac{r^2(n - 2)}{1 - r^2}}$$

satisfies a "t" distribution, and hence can be used to evaluate the confidence level of agreement with the standard "t" table.

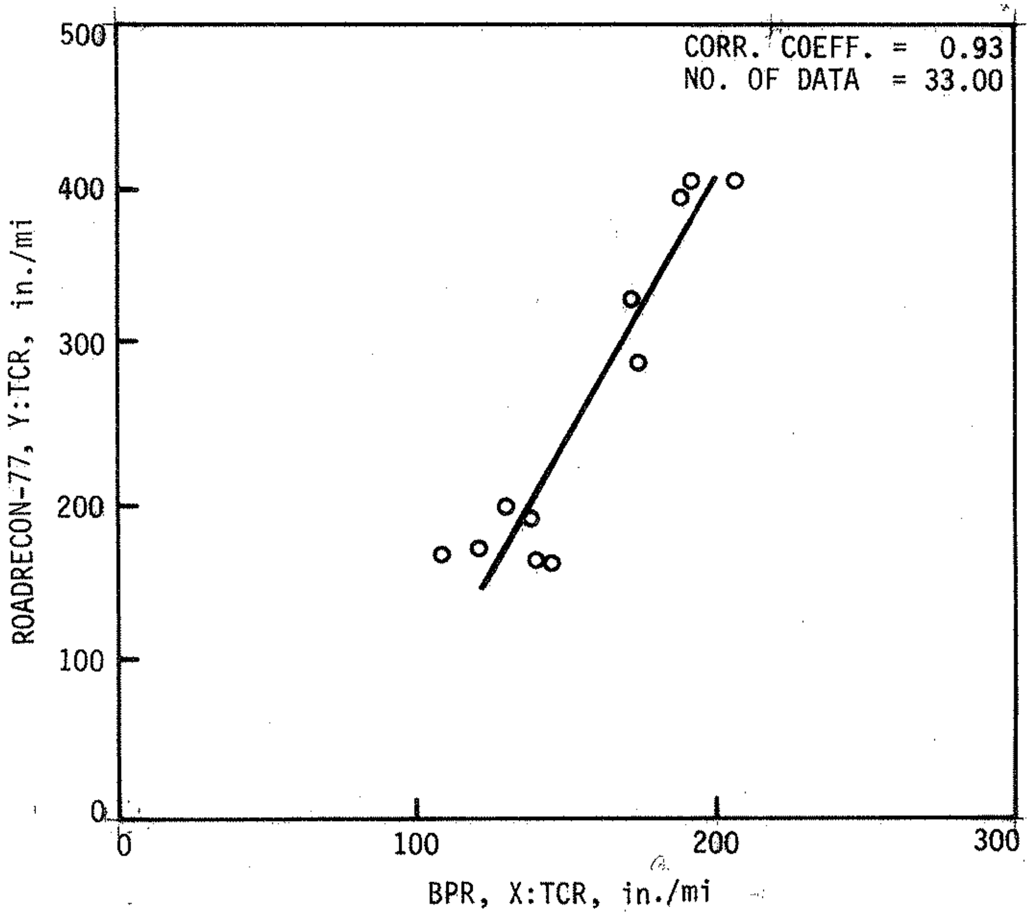


Fig. C.1. BPR vs ROADRECON-77 (TCR).

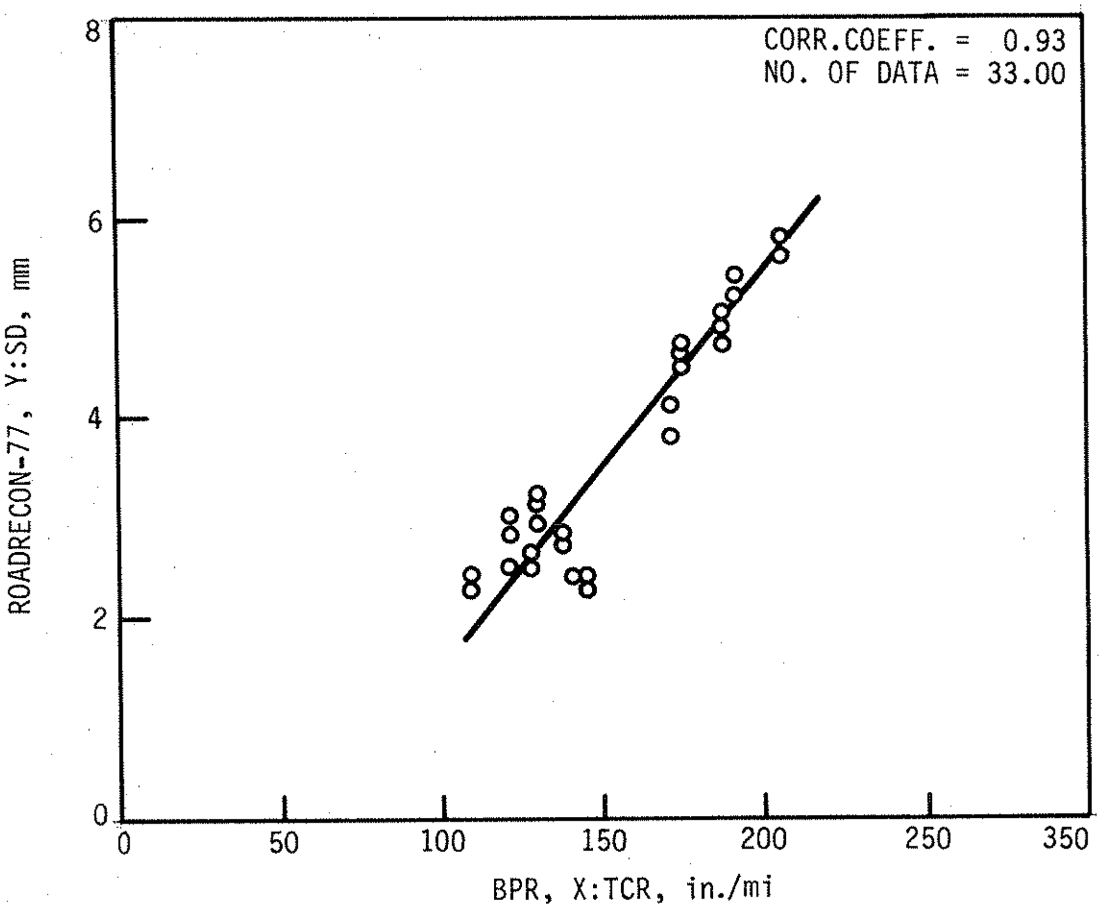


Fig. C.2. BPR vs ROADRECON-77 (SD).

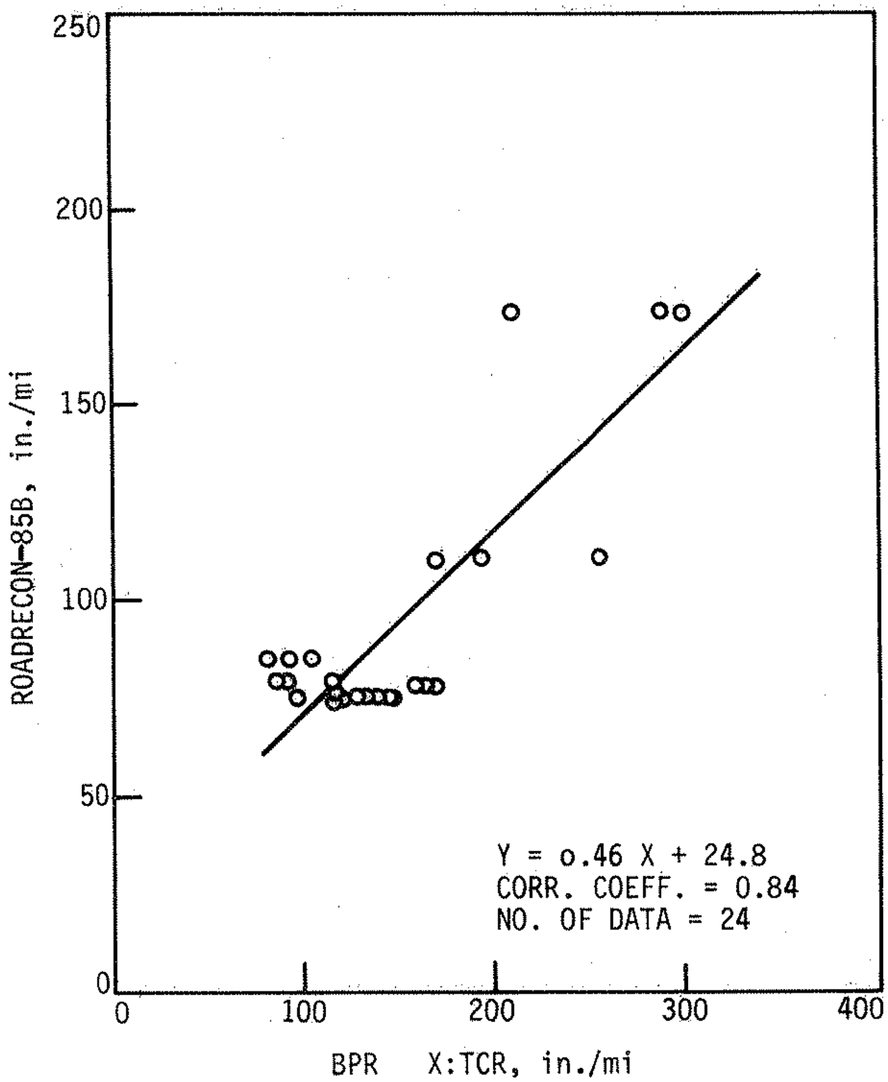


Fig. C.3. BPR vs ROADRECON-85 (TCR).

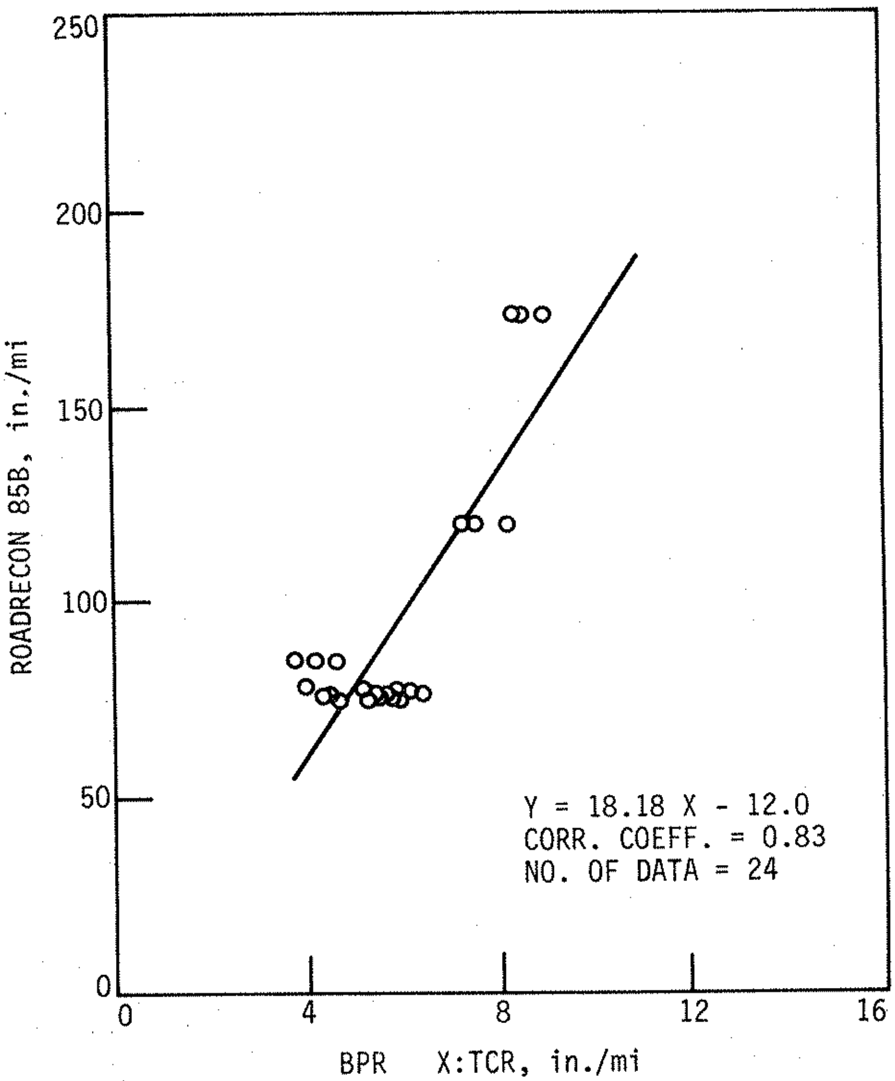


Fig. C.4. BPR vs ROADRECON-85 (SD).

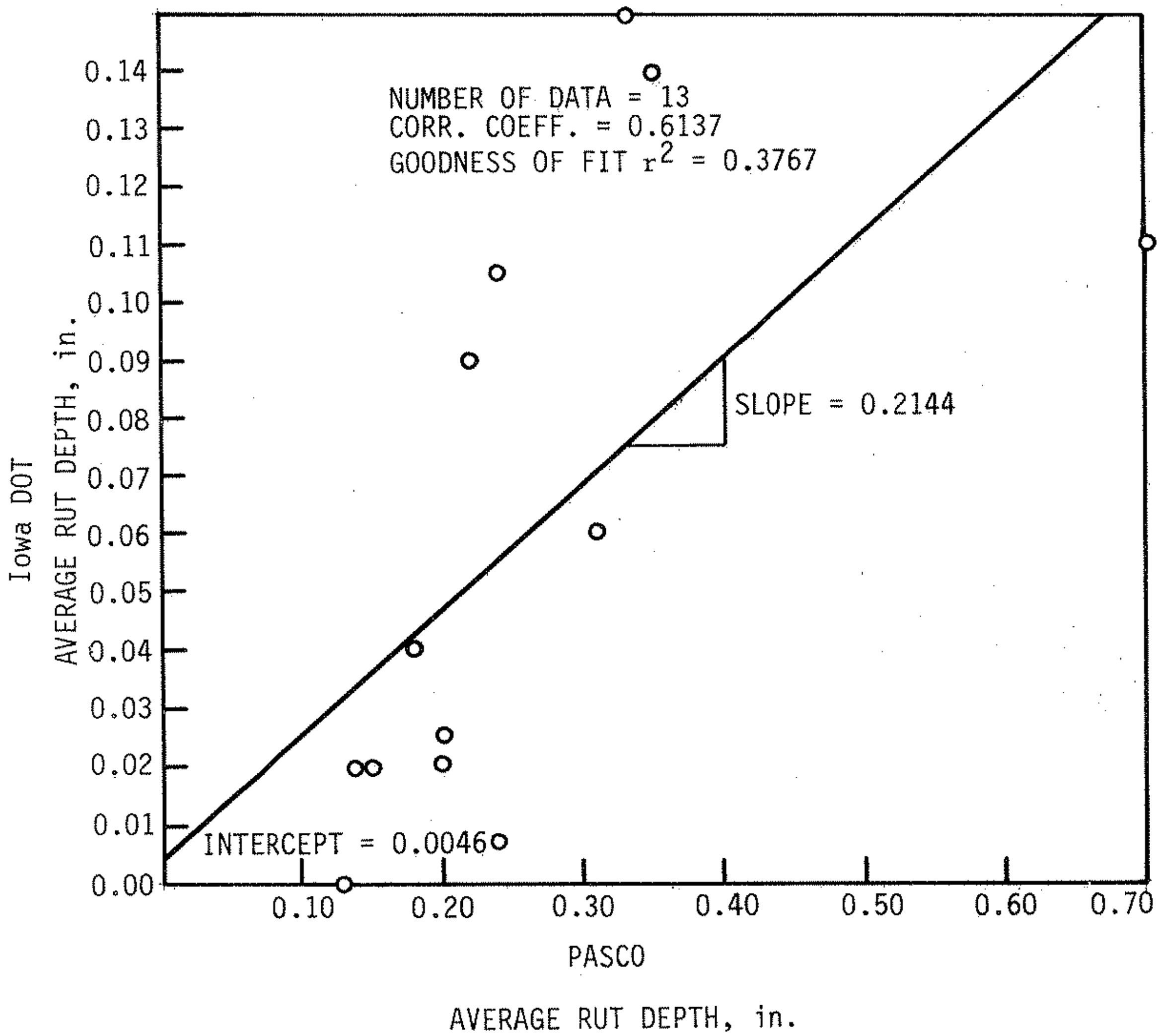


Fig. C.5. Rut depth (PASCO vs Iowa DOT).

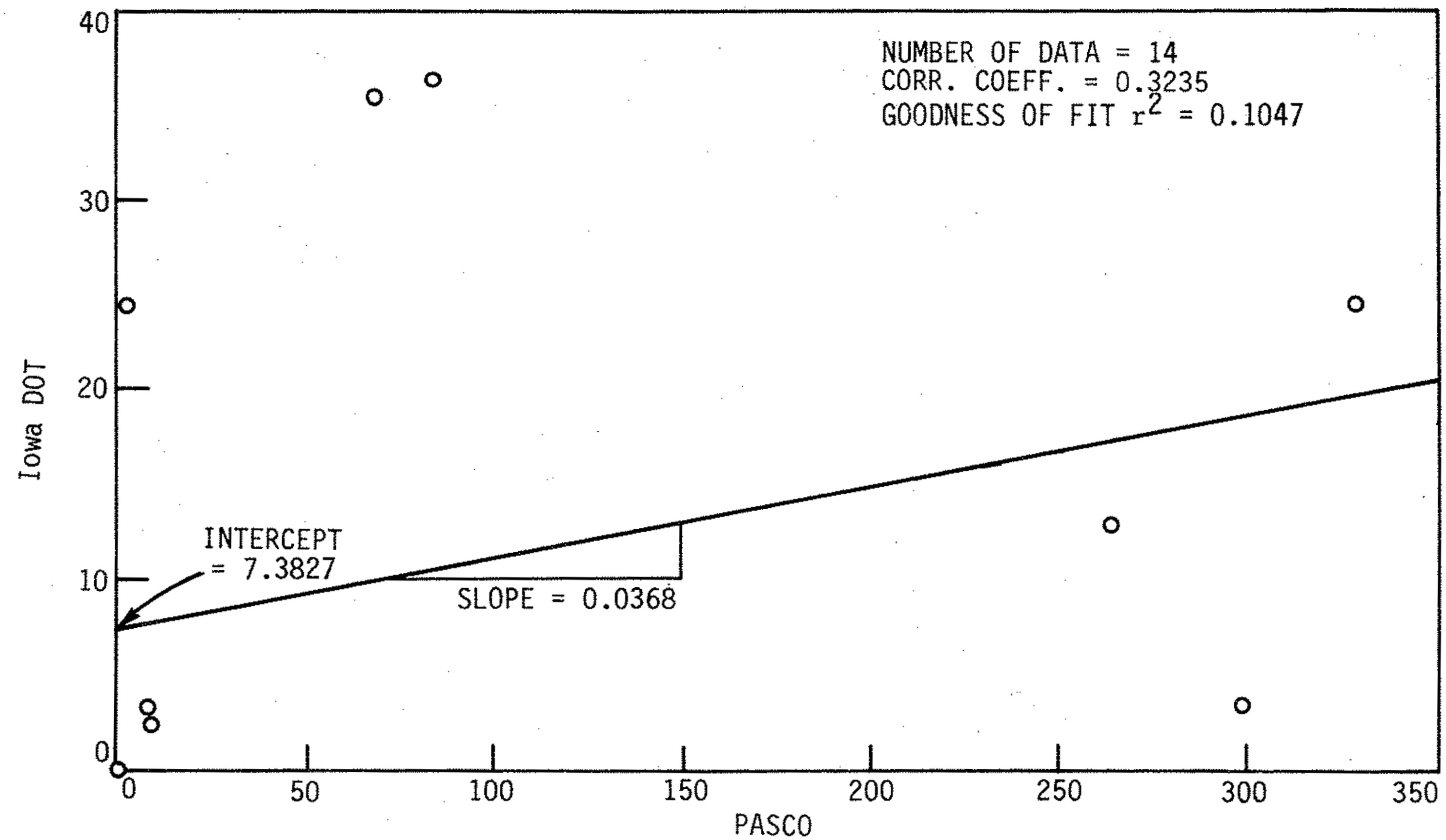


Fig. C.6. Cracks (PASCO vs Iowa DOT).

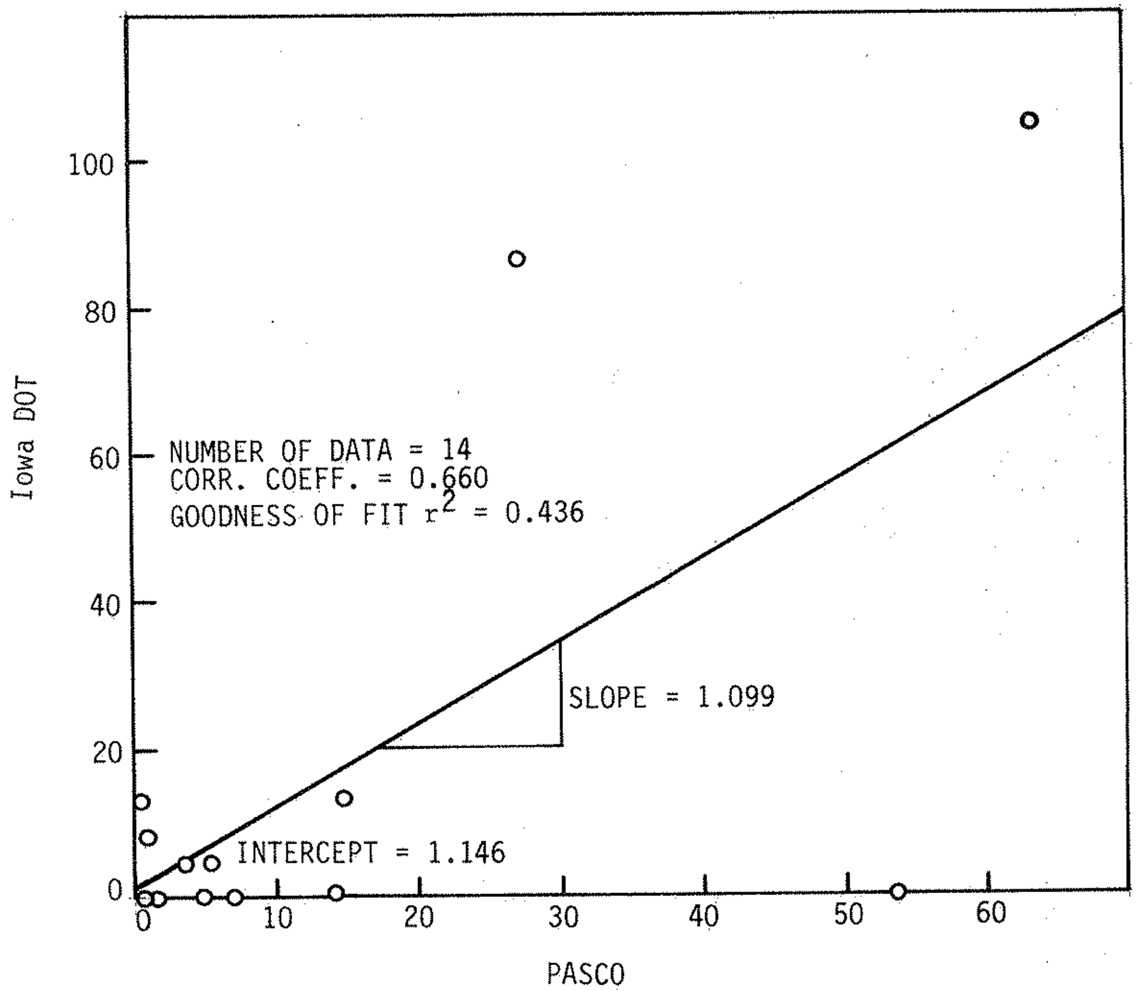


Fig. C.7. Patches (Iowa DOT vs PASCO).

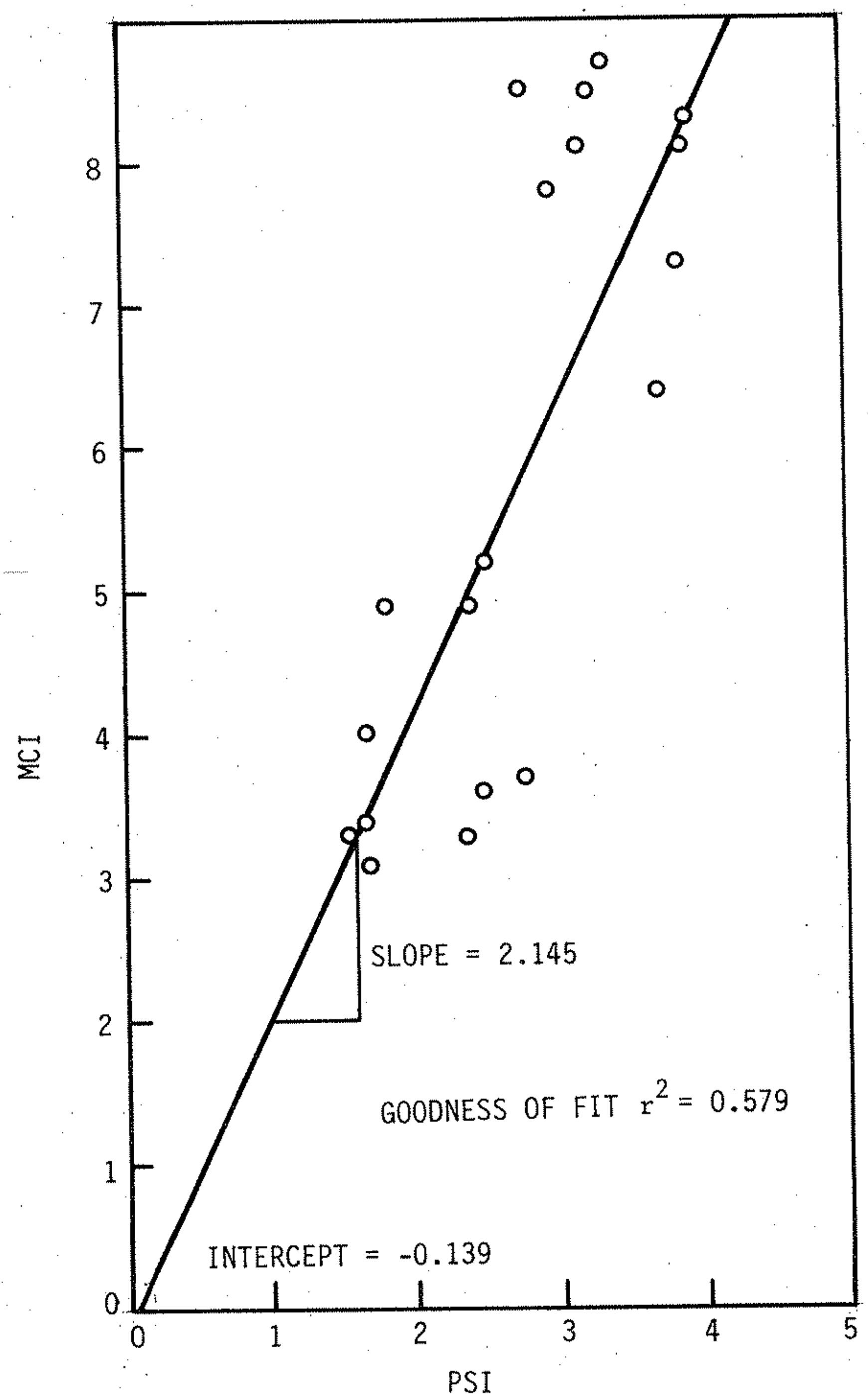


Fig. C.8. MCI vs PSI.

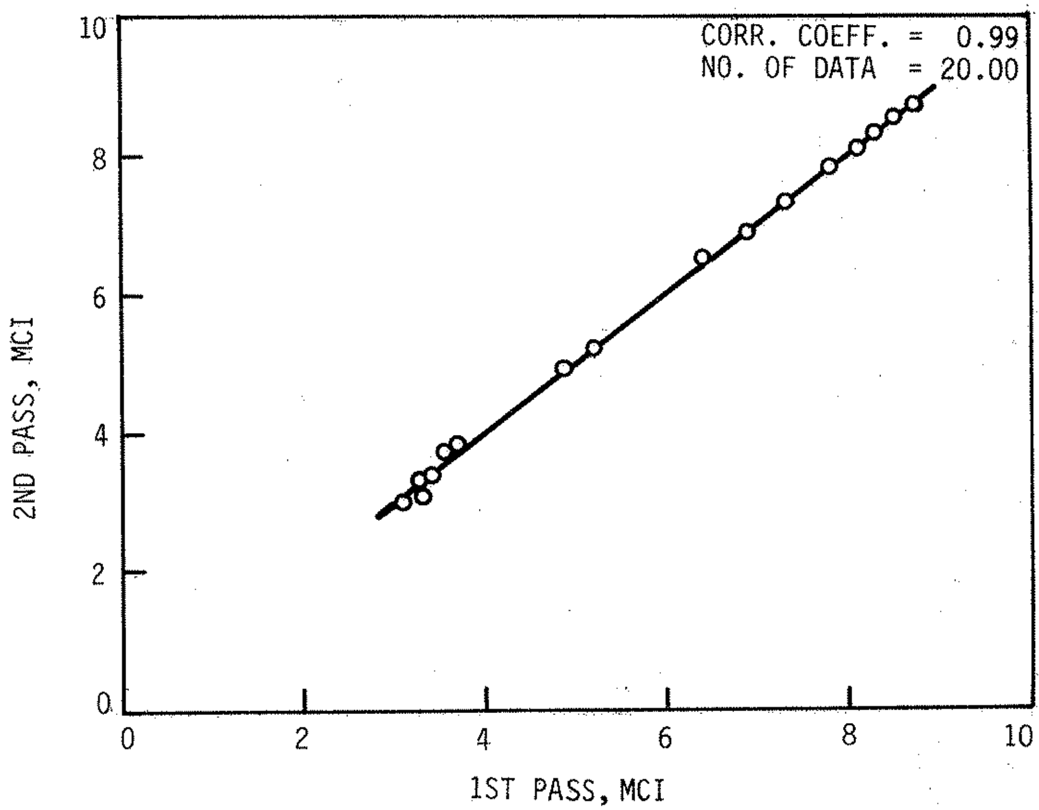


Fig. C.9. MCI (1st pass vs 2nd pass).

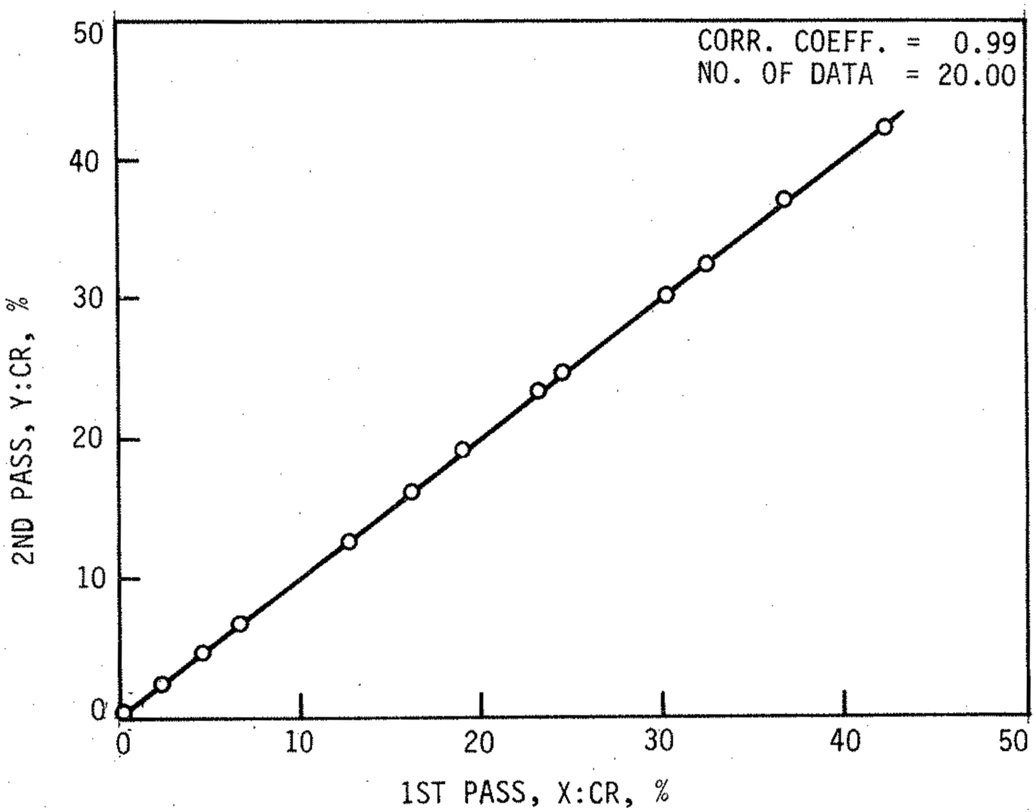


Fig. C.10. ROADRECON-70 (1st pass vs 2nd pass).

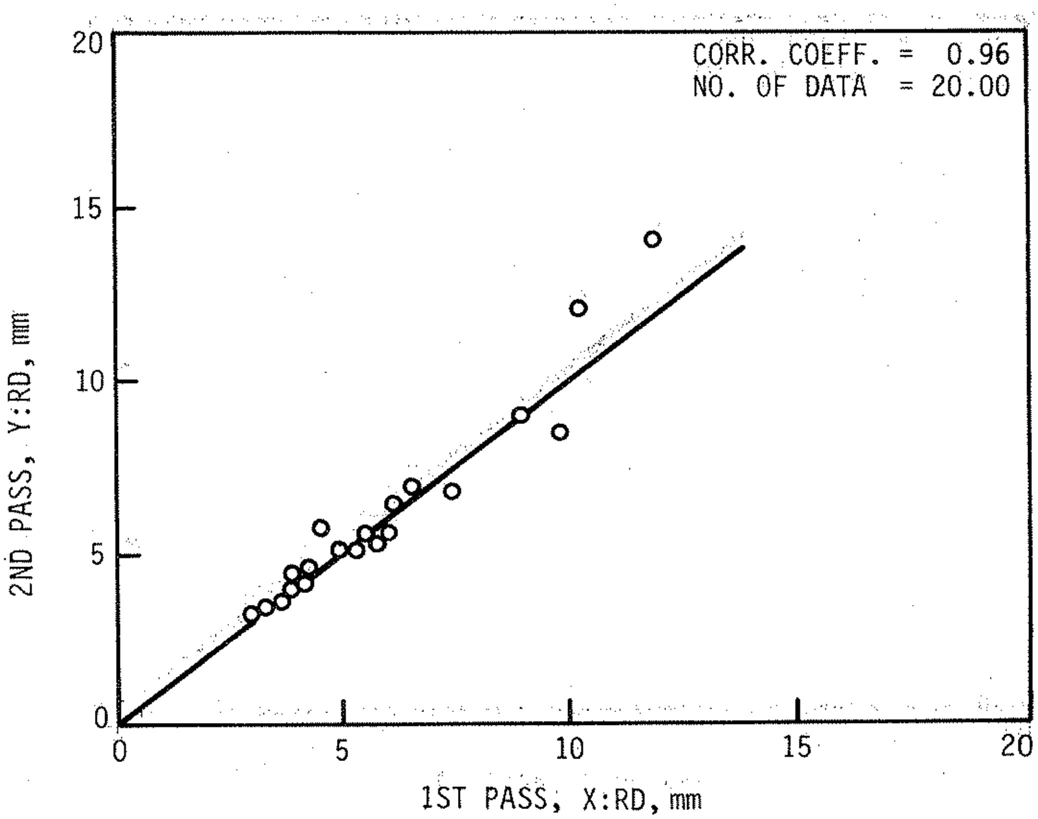


Fig. C.11. ROADRECON-75 (1st pass vs 2nd pass).

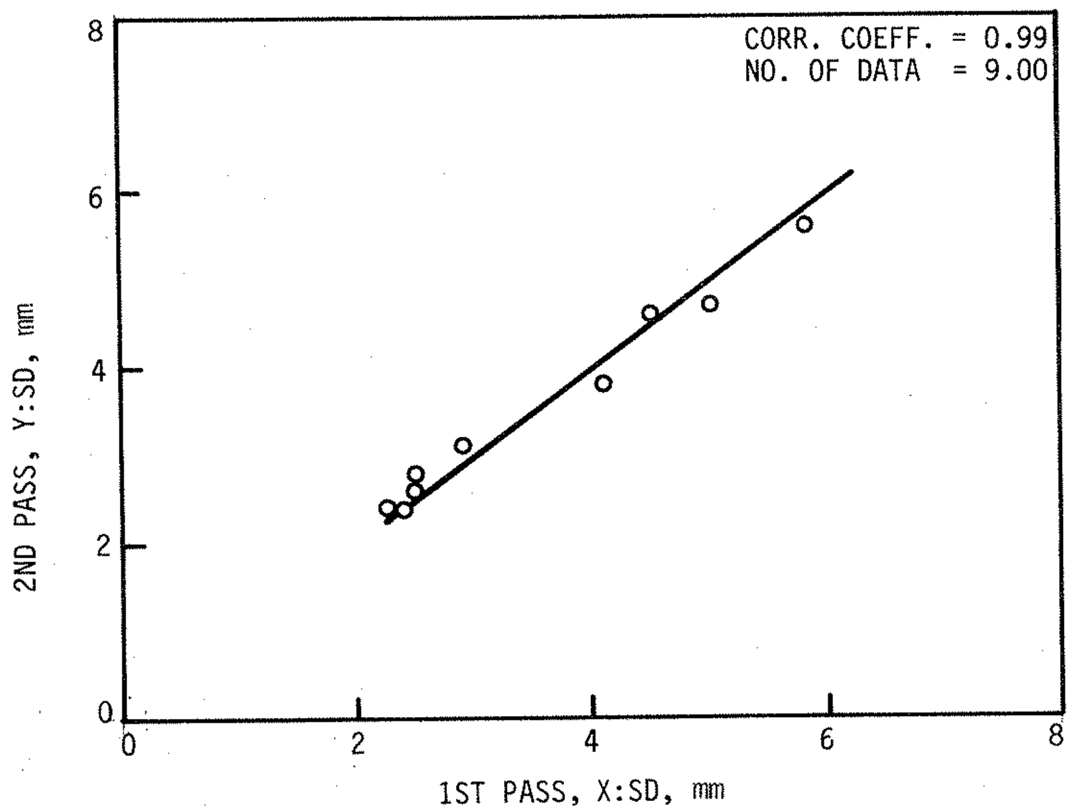


Fig. C.12. ROADRECON-77 (1st pass vs 2nd pass).

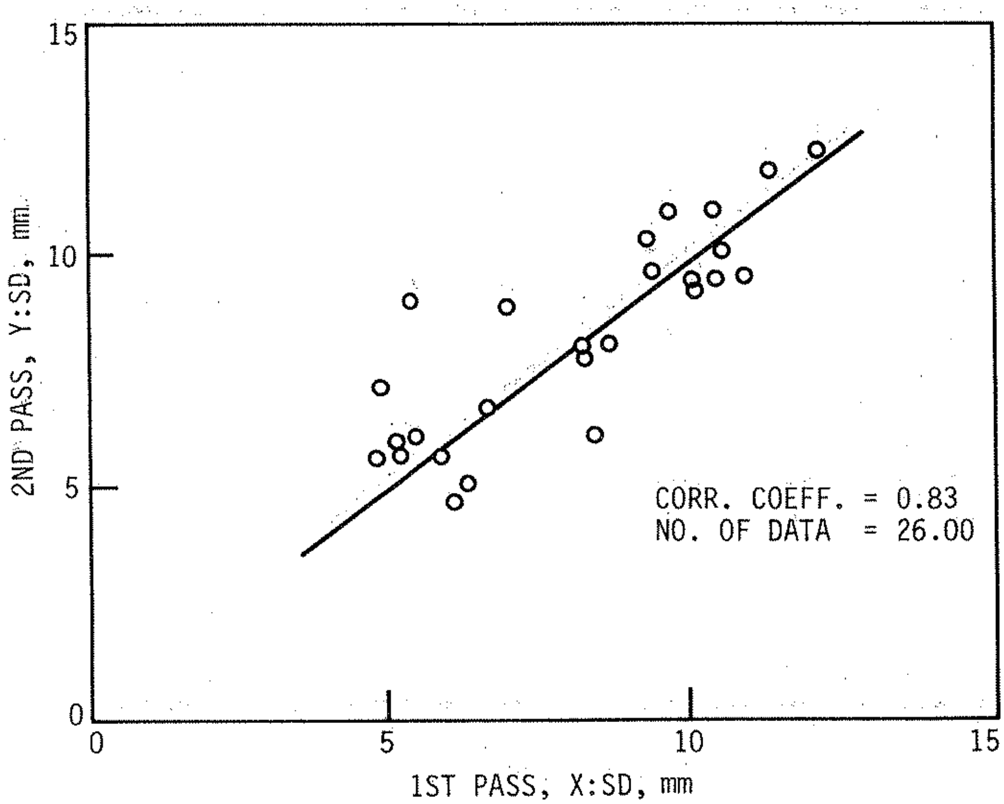


Fig. C.13. ROADRECON-85B (1st pass vs 2nd pass).