HIGHWAY RESEARCH REPORT

ROAD ROUGHNESS CORRELATION STUDY

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SYNOPSIS

This report is an evaluation of four roughness measuring devices used, along with both a Present Serviceability Index and a panel type (PSR) rating system.

P.S.I. as used in this study is the abbreviation for Present Serviceability Index and PCA is the abbreviation for Portland Cement Association. Present Serviceability Index is a number rating system indicating the ability of a specific section of pavement to serve high-speed, high-volume, mixed (truck and automobile) traffic in its existing condition.

The Portland Cement Association developed the PCA Road Meter, a simple, inexpensive device installed in a conventional automobile to measure the number and magnitude of vertical deviations per mile of road between the body of the automobile and the center of the rear axle housing. From these measurements, the sum of squares of road car deviations can be calculated and correlated with Slope Variance of the Chloe Profilometer.

The Mays Road Meter is a simple, mechanical type instrument that has been developed for use in an automobile to produce a tape presentation representative of the surface roughness of the pavement section traversed. The Mays Road Meter and the Bureau of Public Roads Roughometer, hereafter referred to as the BPR Roughometer, are similar in that both give a readout or representation in inches per mile roughness.

Previously a correlation was made between the PCA Road Meter and the Chloe Profilometer with emphasis on accuracy, repeatability and correlation ability to the Chloe Profilometer. In this study, these four roughness measuring devices (the PCA Road Meter in an automobile, the PCA Road Meter in a station wagon, the Mays Road Meter in the same automobile and the BPR Roughometer) were tested for accuracy, repeatability, and correlation ability with each other and a panel type (PSR) rating system. The variables in the operation of these devices were studied to determine their effects on the test results. These variables were vehicle operating speed and temperature.

The following conclusions were reached:

1. The Mays Road Meter is the better of the four roughness measuring devices considering all variables and conditions.

3. In the authors' opinion, for the data available, there are acceptable correlations between any of the five methods of obtaining roughnesses of either rigid (concrete) or flexible (hot mix or surface treatment) pavements. Correlation equations are found in Table 2.

4. The effect of temperature change on PCA Road Meter or Mays Road Meter data can be corrected by using the following equations:

Corrected PCA Road Meter $\sum(D)^2$ = Basic PCA Road Meter $\sum(D)^2$ + 0.040 (70-T), where T = temperature in °F

Corrected Mays Road Meter in/mi. Roughness = Basic Mays Road Meter in/mi. Roughness +0.5(70-T), where T = temperature in °F.

5. Tests indicated $\sum(D)^2$ for the PCA Road Meter or in/mi. roughness for the Mays Road Meter varies with any change in speed of the vehicle, therefore affecting results. Some error is still inherent in the results using the correction equations, however for the present, since the error is small the following equations will be used for speed corrections:

PCA Road Meter, Slope Variance = (1.18 - 0.01 MPH) $\sum(D)^2$ + 0.8

Corrected Mays Road Meter in/mi. Roughness = Basic Mays Road Meter in/mi. Roughness + 1.5 (50-S), where S = speed in mph.

6. The Mays Road Meter should not be operated at 60 mph because of lack of reliability of the speed correction equation at that speed.

7. Both the PCA Road Meter and the Mays Road Meter are relatively inexpensive, with the cost of obtaining and installing probably less than $1.000.00.

8. The PCA Road Meter and the Mays Road Meter utilize an ordinary sedan without a trailer and at speeds resembling normal highway speeds, 40 or 50 mph.

9. The BPR Roughometer requires a trailer, is more costly, and operates at a somewhat slower speed of 20 mph.

Recommendations are as follows:

1. The Louisiana Department of Highways should purchase a Mays Road Meter and operate their present PCA Road Meter and the Mays Road Meter in the same vehicle, preferably an automobile. These two devices operating together in the same vehicle would be a very advantageous research tool.

2. All present roughness testing devices should be retained for specialized uses or for emergency status.

3. The PCA Road Meter and the Mays Road Meter should be operated at a basic speed of 50 mph during testing.

4. Consideration should be given to placing either a PCA Road Meter or a Mays Road Meter in each of the nine districts of the state for use in new construction or maintenance. The authors recommend using the Mays Road Meter for this purpose if this consideration is implemented. These units should be calibrated periodically using established test courses.

INTRODUCTION

The Research and Development Section of the Louisiana Department of Highways has been using a PCA Road Meter to gather information concerning Present Serviceability Indices for the AASHO Correlation Study. The PCA Road Meter has replaced the Chloe Profilometer because the Chloe Profilometer had proven undesirable for this purpose for several reasons, primarily slow operational speed and lack of safety.

This study was conducted to correlate the PCA Road Meter in present use with a PCA Road Meter in another vehicle and with a newer device, the Mays Road Meter. The Mays Road Meter was also evaluated for future use, either by the Research and Development Section or by other units of the Louisiana Department of Highways. The BPR Roughometer was included in this study to have a correlation between any of our present roughness measuring devices in order to be able to interchange equipment in case of breakdown or need for comparative results. This study was conducted as a part of HPR Project 63-4SC, AASHO Correlation Study.

SCOPE

The scope of this study was to define any correlations between the two PCA Road Meters, the Mays Road Meter, the BPR Roughometer, and both a Present Serviceability Index and a panel type (PSR) rating system. Accuracy, repeatability and ability to correlate were to be determined, along with effects of temperature and operational speed of the vehicle upon results. The field worthiness of the several systems was to be examined along with the validity of their respective measurements.

DESCRIPTION OF TESTING DEVICES

The PCA Road Meter

The PCA Road Meter was developed by the Portland Cement Association to afford a rapid method for the measuring of the effect of slope variance on dynamic behavior of the vehicle, this being a factor in obtaining Present Serviceability Indices of pavements. The PCA Road Meter is correlated to the Chloe Profilometer for obtaining the Present Serviceability Indices.

The description of the PCA Road Meter was taken from the report by M. P. Brokow, "Development of the PCA Road Meter, A Rapid Method for Measuring Slope Variance" as follows: The method of obtaining the slope variance makes use of a simple electro-mechanical device, installed in a conventional passenger automobile (in this case a 1966 Ford 4-door sedan). The device measures the number and magnitude of rear axle movements, and these are statistically summed and then correlated with slope variance measured by the Chloe Profilometer.

The device itself consists of a flexible, beaded-steel chain connected to the top center of the rear axle housing in a 1966 Ford 4-door sedan and also a Chevrolet station wagon. The steel chain extends vertically through the truck compartment and then through a small hole in the package deck just back of the rear seat. At this point, the strand passes over a transverse-mounted pulley and is restrained by a tension spring attached to a small post on the package deck near the right side of the body shell. Vertical movement between the center of the axle housing and the package deck is translated to horizontal movement of the chain.

Midway between the pulley and tension spring, a roller micro-switch is attached to the metal chain. Figures 1 and 2 show the beaded-steel chain passing over the transverse mounted pulley and into the assembly containing the roller micro-switch. The micro-switch roller impinges on a switch plate constructed so that the transverse roller movements can be measured in 1/8 inch increments, either plus or minus from a reference standing position of the automobile. High-speed electric counters (Figures 3 and 4) record the accumulations of increments.

The Mays Road Meter

The Mays Road Meter is a simple, mechanical type instrument that has been developed for installation in a passenger automobile capable of producing a reading representative of the surface roughness encountered while

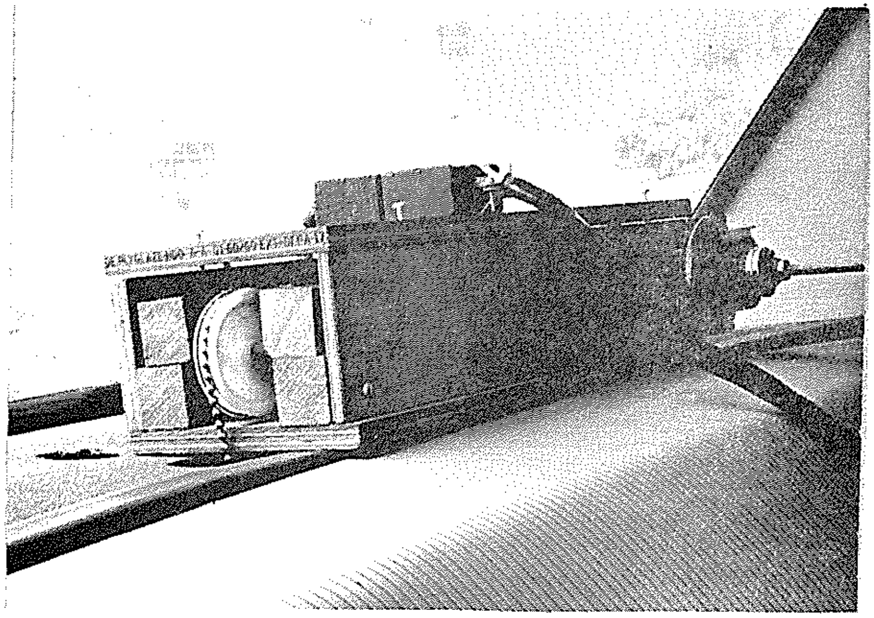


FIGURE 1 - Beaded-Steel Chain, Pulley, and Micro-Switch Assembly, Part of PCA Road Meter in a Car

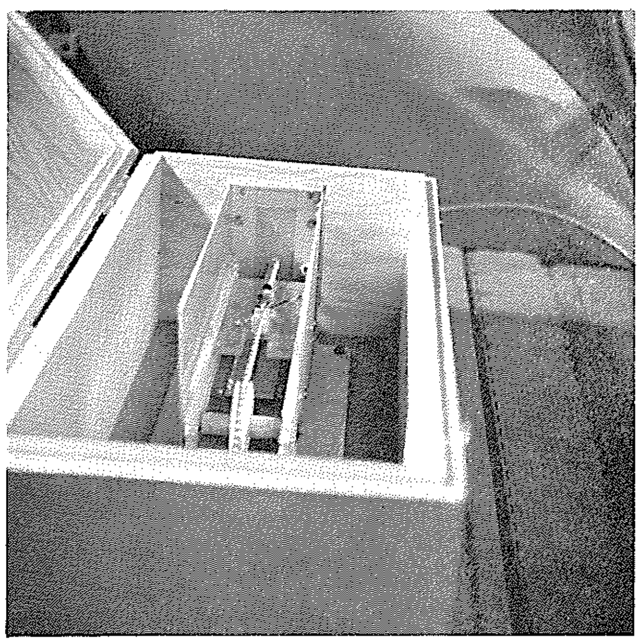


FIGURE 2 - Beaded-Steel Chain, Pulley, and Micro-Switch Assembly, Part of PCA Road Meter in a Station Wagon

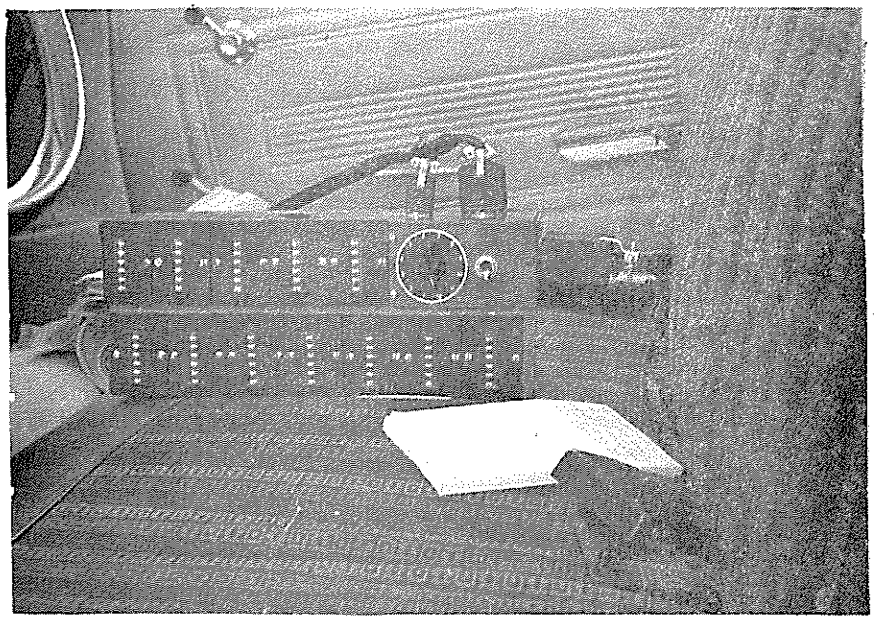


FIGURE 3 - High-Speed Electric Counters for a PCA Road Meter in a Car

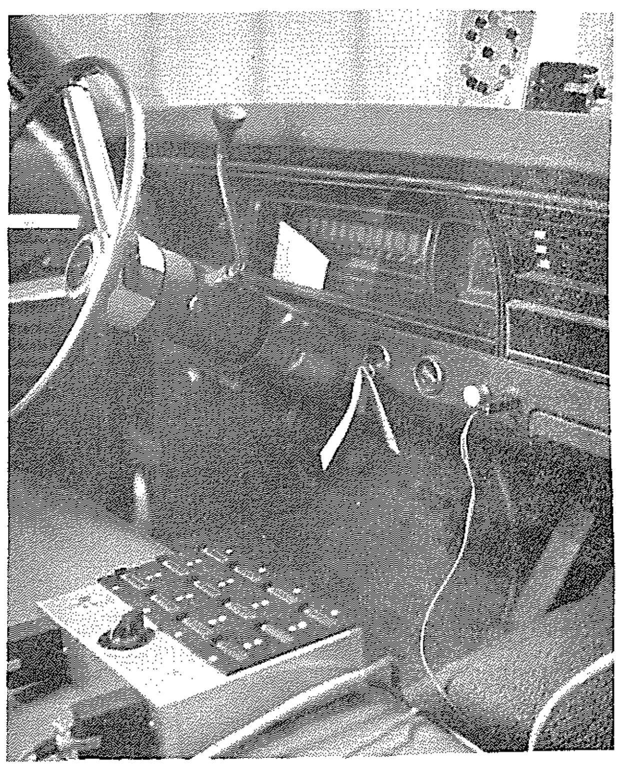


FIGURE 4 - High-Speed Electric Counters for a PCA Road Meter in a Station Wagon

traversing highway sections at normal vehicle speeds. The Mays Road Meter employs the vehicle chassis as the reference plane, just as the PCA Road Meter does, and responds to the variations of vertical distance between the chassis and the rear axle (differential housing) of the car. The Mays Road Meter is shown in Figures 5 and 6.

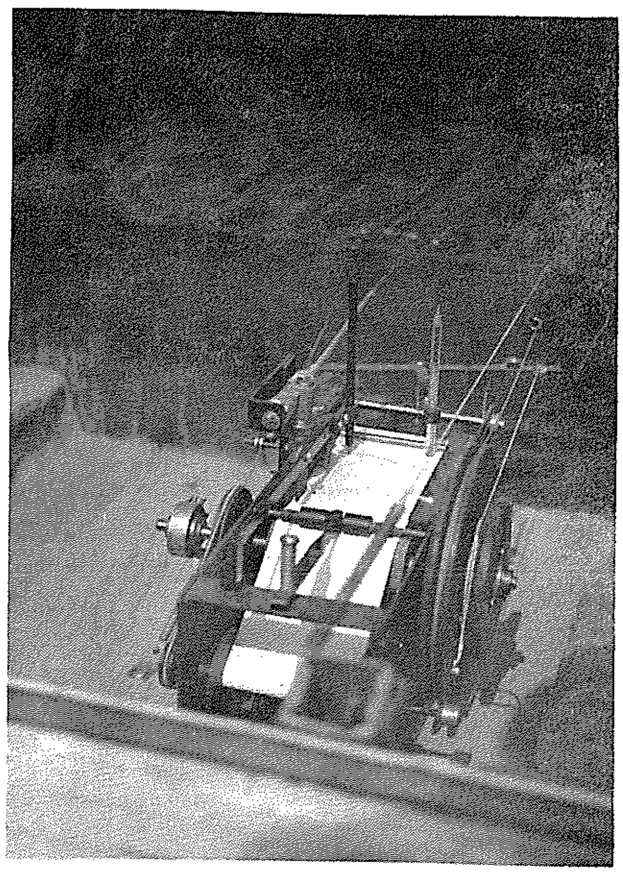
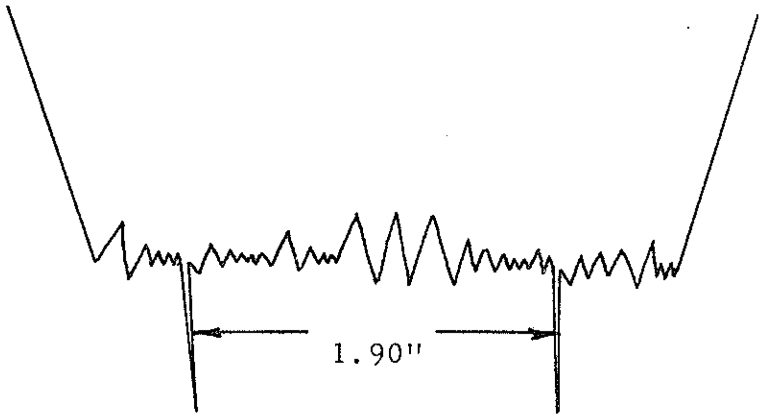


FIGURE 5 - Mays Road Meter Recording Device

FIGURE 6 - Mays Road Meter Control Levers

The description of the Mays Road Meter was taken from the report by M. B. Phillips and Gilbert Swift, "A Comparison of Four Roughness Measuring Systems." A flexible wire cable, attached to the differential housing, extends vertically upward through a small hole made in the floor of the truck compartment. Passing over a fixed pulley, this cable is brought horizontally to the instrument where it wraps around a 7.5 inch diameter wheel and continues to an anchored tension spring. Accordingly, relative vertical motion between chassis and axle produces proportional rotation of this wheel, in one direction for upward axle movement, oppositely for downward movements. The resulting reciprocating motion is linked mechanically to a pen which produces a continuous record on adding machine tape. The same motion, applied through a non-reversing clutch, is employed to advance the tape. The result is a graphic record on which the magnitude of the individual vertical excursions of the axle relative to the chassis are depicted as proportional excursions of the trace while the length of the record represents the sum of all the upward movements of the axle which have occurred. A marking device controlled by the operator permits the beginning and end of each section to be indicated on the record. Figure 7 shows a typical example of the Mays Road Meter presentation on tape.



0.2 Mile Section

$$\text{Roughness} = \frac{1.90 \times 8}{0.2} = 76.0 \text{ in/mi.}$$

FIGURE 7 - Typical Example, Mays Road Meter Presentation on Tape

The indicated roughness is obtained by measuring the length of the record in inches and multiplying by an appropriate constant. This constant is a function simply of the paper drive mechanism and the length of the section. The resulting Roughness is expressed in units of inches per mile, representing the total of the upward excursions (which is necessarily almost one-half of all the vertical excursions) divided by the distance travelled. The basic similarity of this system to the BPR Roughometer will be apparent. However, the additional feature of a pen trace which depicts the magnitude of the separate excursions, coupled with the simplicity of adding only a small recording device inside the vehicle instead of a trailer, makes it a simpler system. In this study the Mays Road Meter was installed in the same automobile as one of the PCA Road Meters.

The BPR Roughometer

The BPR Roughometer (Figures 8 and 9) is an electro-mechanical type system for measuring roughness of a road utilizing a trailer and a towing vehicle. The Roughometer needs no description here since it is a device well known in the highway profession.

FIGURE 8 - BPR Roughometer Trailer

FIGURE 9 - BPR Roughometer Console

METHOD OF PROCEDURE

Repeatability

All four testing devices, the PCA Road Meter in the automobile, the PCA Road Meter in the station wagon, the Mays Road Meter in the same automobile and the BPR Roughometer, were checked for repeatability using two levels of rideability based on visual observations for the flexible pavements. The two levels of rideability were smooth and rough. Twenty runs were made over each type of pavement under the following conditions:

1. Two persons (or equivalent weight of approximately 300 pounds) in front seat of the automobile and station wagon for the two PCA Road Meters and the Mays Road Meter, with no limitations on the towing vehicle for the BPR Roughometer.

2. A full or nearly full tank of gas (no limitations on the tow vehicle for the BPR Roughometer).

3. A constant temperature range (±3 °F.).

4. Wind velocity of 5 mph or less (to eliminate effect of any wind on results).

5. Operations speed of 50 mph and 30 mph for the PCA Road Meters and the Mays Road Meter respectively and 20 mph for the BPR Roughometer.

Temperature Change

The PCA Road Meters and the Mays Road Meter were operated at varying temperatures from 38 °F. to 74 °F, with the other above conditions constant to determine the effects of temperature change on test results. All the runs were made on the smooth section. Information gathered on these runs was used to derive correction equations for the effects of temperature change on the PCA Road Meter's $\sum(D)^2$ results (used for obtaining P.S.I.'s) and the Mays Road Meter's in/mi. roughness results. Effects of temperature were not checked on the BPR Roughometer. This may be done at a later date.

Vehicle Operating Speed

Vehicle operating speed is a variable that also affects test results. Twelve sections (4 concrete, 5 hot mix and 3 surface treatment) were used to check this variable. These twelve sections were selected because of their variety of types and complete range of roughness (smooth, medium and rough).

Two runs were made on each section at each different speed (30, 40, 50 and 60 mph). The PCA Road Meters and the Mays Road Meter were checked for speed variation only. The BPR Roughometer was deleted from this phase, as it is operated at a set standard speed of 20 mph.

Correlation of the Testing Devices

Correlations were made between all the testing devices plus a panel type (PSR) rating. A correlation was made previously in the AASHO Correlation Study (HPR 63-4SC) between the PCA Road Meter (in the automobile) and the Chloe Profilometer for obtaining Present Serviceability Indices. If need be, Chloe P.S.I.'s could be obtained by using these correlation equations in converting back from the PCA Road Meter, although this is not altogether desirable. The Chloe Profilometer was not included in this present correlation of testing devices because of this previous correlation and also because of time delays, extra cost and the inherent breakdown rate of the Chloe Profilometer.

Fifty one-half mile length sections, consisting of 20 rigid (concrete), 22 hot mix and 8 surface treatment sections, were selected and run for these correlations. Three runs were made over each section at a speed of 50 mph for the PCA Road Meters and the Mays Road Meter, while the BPR Roughometer was run three times over each section at 20 mph. A panel type (PSR) rating was made on each test section by the operators of the vehicles and the personnel involved in this study. An average panel rating was used for the purpose of obtaining additional information only and not intended to be used for direct comparisons of correlation data. Therefore no repeatability data will be shown for the panel rating.

DISCUSSION OF RESULTS

Repeatability

The repeatability runs for all four testing devices yielded variable results, ranging from good to questionable. Generally, tests on the rough pavement section produced better repeatability results than the tests on the smooth pavement section. The statistical data on the repeatability runs is illustrated in Table 1.

TABLE 1
REPEATABILITY DATA

Variable	Test	Smooth Section Nicholson Drive		Rough Section Essen Lane		Overall Ave.
		50 mph	30 mph	50 mph	30 mph	
PCA Car Corrected $\sum(D)^2$	Mean	8.76	5.00	66.37	38.65	-
	Standard Dev.	0.468	0.453	3.876	1.910	-
	Coeff. of Var., Percent	5.3	9.0	5.8	4.9	6.25
PCA Sta. Wagon Corrected $\sum(D)^2$	Mean	8.17	5.42	83.08	34.99	-
	Standard Dev.	0.927	1.112	4.341	2.777	-
	Coeff. of Var., Percent	11.3	20.5	5.2	7.9	11.22
Mays Road Meter Corrected in/mi.	Mean	64.50	38.15	255.58	185.07	-
	Standard Dev.	4.165	3.165	14.986	5.190	-
	Coeff. of Var., Percent	6.4	8.3	5.9	2.8	5.85
BPR Roughometer in/mi. Roughness	Mean	-	20mph 78.40	-	20mph 190.70	-
	Standard Dev.	-	0.821	-	3.389	-
	Coeff. of Var., Percent	-	1.0	-	1.8	1.40

Coefficient of variation ranged from 1.0% with the BPR Roughometer on the smooth section to 20.5% with the PCA Road Meter in the station wagon over the smooth section at 30 mph. However, previous work with the PCA Road Meter had shown better repeatability than this; therefore there is some room for question concerning these results. The BPR Roughometer has the lowest overall coefficient of variation, followed in order by the Mays Road Meter, the PCA Road Meter in the automobile and the PCA Road Meter in the station wagon.

Temperature Change

Data analysis shows there is a small change of either $\sum(D)^2$ for the PCA Road Meters or in/mi. roughness for the Mays Road Meter due to the change in temperature.

The equations derived in this study for temperature change corrections are as follows:

Corrected PCA Road Meter $\sum(D)^2$ = Basic PCA Road Meter $\sum(D)^2$ +0.040 (70-T), where T = temperature in °F.

Corrected Mays Road Meter in/mi. Roughness = Basic Mays Road Meter in/mi. Roughness +0.5 (70-T), where T = temperature in °F.

Study temperature ranged from 38°F. to 74°F. The PCA Road Meter temperature correction equation in this study is slightly different than the equation used in the PCA Road Meter Correlation Study (AASHO Correlation Study Interim Progress Report No. 2). The equation in this study is the latest revised temperature correction equation. Temperature correction data points and curves are shown in Figure 10 of the Appendix.

Vehicle Operating Speed

Tests on a limited scale were made with the PCA Road Meter and the Mays Road Meter operating at speeds of 30, 40, 50 and 60 mph. The Research and Development Section of the Louisiana Department of Highways found, as did the Portland Cement Association that tests indicated $\sum(D)^2$ for the PCA Road Meter varies with the speed of the vehicle. Test results indicated that some error still existed using the PCA recommended equation for speed correction. However, for the present, this recommended equation will be used for any speed correction. The equation for speed correction is as follows:

$$\text{Slope Variance} = (1.18 - 0.01\ \text{MPH}) \sum(D)^2 + 0.8$$

Curves showing $\sum(D)^2$ results for speed changes using this equation for the PCA Road Meter are found in Figure 11 of the Appendix. Tests also indicated that the in/mi. roughness for the Mays Road Meter varied slightly with the speed of the vehicle.

The recommended equation used for any speed change correction in the Mays Road Meter results is as follows:

Corrected Mays Road Meter in/mi. Roughness = Basic Mays Road Meter in/mi. Roughness + 1.5(50-S), where S= speed in mph.

It is recommended not to operate the Mays Road Meter at 60 mph as this equation is less reliable at 60 mph. The basic operating speed should be 50 mph, with the correction equation used for slower speeds. Curves showing roughness results for speed changes for the Mays Road Meter are found in Figure 12 of the Appendix.

Correlation Results

Correlations were made between five methods of obtaining roughnesses both on rigid (concrete) and flexible (hot mix and surface treatment) pavements. These five methods were: (1) use of a PCA Road Meter in an automobile, (2) use of a PCA Road Meter in a station wagon, (3) use of a Mays Road Meter in an automobile, (4) use of a BPR Roughometer and (5) a panel type (PSR) rating.

Ten basic adjusted equations converting results from one method to another method on each type pavement are shown in Table 2 with their respective coefficients of determination, R^2.

These equations found in Table 2 were decided upon and adjusted from statistical equations listed in Table 4 of the Appendix. The equations in Table 4 were for all the various conditions and type pavements available. Table 5 of the Appendix is an additional table which gives the various coefficients of determination for the statistical equations found in Table 4 of the Appendix and is presented in this table for an easy visual comparison. Decisions on which equations to use were made with considerations given to the best statistical results and most logical type equations to use. Adjustments were made to equalize small errors inherent in these equations when completing a closed circle type of conversion, for example converting PCA Road Meter results to PSR, thence to Mays Road Meter results and back to PCA Road Meter results.

Comparison of repeatability data (average coefficients of variation) from this study indicates the following order of equipment with the best repeatability: (1) BPR Roughometer - 1.4%, (2) Mays Road Meter - 5.85%, (3) PCA Road Meter in an automobile - 6.25%, (4) PCA Road Meter in a station wagon - 11.22%. A possible factor in the BPR Roughometer superiority in repeatability is due to its

TABLE 2

ADJUSTED EQUATIONS FOR GENERAL USE

NO.	Y	X	PCC (CONCRETE)	R^2	FLEXIBLE (HM & ST)	R^2
1	PCA Car - $\sum(D)^2$	PCA Station Wagon - $\sum(D)^2$	Y= 12.22 + 0.539X	0.870	Y= 6.22 + 0.714X	0.912
2	PCA Car - $\sum(D)^2$	Mays Meter - in/mi.	Y= -7.38 + 0.260X	0.765	Y=-12.98 + 0.316X	0.932
3	PCA Car - $\sum(D)^2$	PSR (Rating)	Y= 91.00 - 19.700X	0.797	Y= 75.50 - 17.235X	0.684
4	PCA Car - $\sum(D)^2$	BPR Rough. -in/mi.	Y= -6.19 + 0.274X	0.787	Y=-11.89 + 0.273X	0.733
5	Mays Meter - in/mi.	PCA Sta. Wagon $\sum(D)^2$	Y= 58.95 + 2.757X	0.938	Y= 61.42 + 2.260	0.947
6	Mays Meter - in/mi.	PSR (Rating)	Y= 363.51 - 71.400X	0.855	Y= 376.39 - 86.494X	0.792
7	Mays Meter - in/mi.	BPR Rough - in/mi.	Y=-28.09 + 1.336X	0.920	Y= -24.82 + 1.060X	0.833
8	PCA Sta. Wag. $\sum(D)^2$	PSR (Rating)	Y= 175.00 - 45.163X	0.723	Y= 130.50 - 35.763X	0.736
9	PCA Sta. Wag. $\sum(D)^2$	BPR Rough. - in/mi.	Y= -29.70 + 0.470X	0.931	Y= -36.00 + 0.461X	0.461
10	PSR (Rating)	BPR Rough.- in/mi.	Y= 5.40 - 0.018X	0.818	Y= 4.85 - 0.014X	0.833

Average R^2 for Roughness Equations Involving the Following Equipment or Method:
PCA Car - 0.810, PCA Station Wagon - 0.815, Mays Road Meter - 0.873
BPR Roughometer - 0.790, PSR (Rating) - 0.778

narrower range of readings. This is not desirable because of a lesser ability to differentiate roughness levels. Counter readings give only a summed up amount of movement to a whole number in inches per mile, therefore the possibility of obtaining the same number of inches per mile is increased. Another factor, of course, is the BPR Roughometer has standardized and specified apparatus (tires, springs, weight, integrator, dash pots, etc.)

Comparison of average coefficients of determination indicates the following order of equipment with the best correlation ability: (1) Mays Road Meter - .873, (2) PCA Road Meter in a station wagon - .815, (3) PCA Road Meter in an automobile - .810, and (4) BPR Roughometer - .790.

The following is an overall rating of each method of obtaining roughnesses based on repeatability, accuracy, correlation ability, operator's and supervisor's rating and practicability or advantages of one method compared to another:

(1) Mays Road Meter
(2) PCA Road Meter in an automobile
(3) PCA Road Meter in a station wagon
(4) BPR Roughometer

This correlation study was undertaken and this report prepared in order to give a comparison of these various roughness testing devices, so that one specific device would be recommended for use as the basic roughness measuring instrument for survey type data throughout the State. The Chloe Profilometer was not included in this study for reasons which will not be enumerated in this report. However assuming the Chloe Profilometer to be the most accurate device as determined from the report mentioned as Reference Number 2, and since most of the test sections were AASHO Test Sections with Chloe Profilometer data available, then an indication of accuracy was determined from a broad comparison of the data obtained on this study and previous data available. It is realized that a continuing process of correlation or calibration will have to be done both periodically and every time a new vehicle is used or an old vehicle is repaired or changed in some way that will affect readings. This report was intended to show if good correlations could be obtained and which type device would be the best to use for this State's survey needs.

The following Table gives the comparisons of the four road roughness devices and was primarily taken from Texas Transportation Institute and Texas Highway Department Cooperative Research Report 32-10.

TABLE 3

COMPARISON OF ROAD ROUGHNESS DEVICES

Description	PCA Car	PCA Sta. Wg.	Mays Road Meter	BPR Rough.
1. Apparatus	Car Only	Sta. Wg. Only	Car Only	Trailer and Sta. Wagon
2. Basic Response	Height	Height	Height	Height
3. Proportionality	Square-law	Square-law	Linear	Linear
4. Accepted Designation of Measurement	$\sum(D)^2$, sum of Road-car Deviations Squared	$\sum(D)^2$, sum of Road-car Deviations Squared	Roughness Index	Roughness
5. Speed While Measuring	40 or 50 mph	40 or 50 mph	40 or 50 mph	20 mph
6. Speed While Travelling to and from Sections	Legal Limit	Legal Limit	Legal Limit	Legal Limit
7. In-field Set-Up Time	1 Minute	1 Minute	None	5 Minutes
8. In-field Set-Up Requirements	Stop Vehicle to Set to Zero	Stop Vehicle to Set to Zero	None	Lower Wheel, Hook up Roughness Integrator and Counters
9. Maximum Section Length	Limited Only By Roughness Exceeding the Counter Cap.	Limited Only By Roughness Exceeding the Counter Cap.	Unlimited	Limited Only By Roughness Exceeding the Counter Cap.
10. Minimum Section Length	Not Recomm. for less than 0.1 mile	Not Recomm. for less than 0.1 mile	Not Recomm. for less than 0.1 mile	Not Recomm. for less than 0.1 mile
11. Data Presentation Form	Plurality of Numerical Counters	Plurality of Numerical Counters	Length of Chart Record	Single Numerical Counter
12. Location of Presentation	Adjacent to Driver	Adjacent to Driver	Adjacent to Driver or in Trunk	Adjacent to Driver
13. Determination of Section Length	Car Odometer or Roadside Marker	Car Odometer or Roadside Marker	Car Odometer or Roadside Marker	Counter
14. In-field Data Requirements (when Measuring Sections of Known Length)	12 Counter Readings at End of Each Section and Reset Count	12 Counter Readings at End of Each Section and Reset Count	Merely Keep Track of Sequence in which the Sections are Traversed	One Reading at End of Each Section
15. In-field Adjustments	Frequent Zero Adjustment Recommended. Requires Vehicle Halt	Frequent Zero Adjustment Recommended. Requires Vehicle Halt	None Required	Frequent Check of Dash-pot Fluid Level
16. At-home Data Processing	Summing and Tabulating	Summing and Tabulating	Measuring the Chart Lengths and Tabulating	Tabulating (May be Done in Field)
17. Additional Data Obtainable from Record	Frequency Distribution of Roughness Heights	Frequency Distribution of Roughness Heights	Approximate Location and Heights of Roughness Within Sections	None
18. Maintenance Requirements	Frequent Polishing of the Commutator to Assure Contact	Frequent Polishing of the Commutator to Assure Contact	Minimal	Frequent Servicing of Grease Fitting and Dash-Pot

CONCLUSIONS

1. The Mays Road Meter is the better of the four roughness measuring devices considering all variables and conditions.

2. All four roughness measuring devices are capable of good repeatability.

3. The Mays Road Meter has the better ability to correlate between the four units, followed in order by the two PCA Road Meter and the BPR Roughometer.

4. In the authors' opinion, for the data available, there are acceptable correlations between any of the five methods of obtaining roughnesses of either rigid (concrete or flexible (hot mix or surface treatment) pavements. Correlation equations are found in Table 2.

5. If need be, results using any of these roughness measuring devices could be converted to Chloe Present Serviceability Indices through use of the correlation equations found in the AASHO Correlation Study (Chloe Profilometer - PCA Road Meter Correlation), although this is not altogether desirable.

6. The effect of temperature change on PCA Road Meter or Mays Road Meter data can be corrected by using the following equations:

Corrected PCA Road Meter $\sum(D)^2$ = Basic PCA Road Meter $\sum(D)^2 + 0.040\,(70 - T)$, where T = temperature in °F.

Corrected Mays Road Meter in/mi. Roughness = Basic Mays Road Meter in/mi. Roughness + 0.5 (70 - T), where T = temperature in °F.

7. Tests indicated $\sum(D)^2$ for the PCA Road Meter or in/mi. Roughness for the Mays Road Meter varies with any change in speed of the vehicle, therefore affecting results. Some error is still inherent in the results using the correction equations, however for the present, the following equations will be used for speed corrections:

PCA Road Meter, Slope Variance = (1.18 - 0.01 MPH) $\sum(D)^2 + 0.8$

Corrected Mays Road Meter in/mi. Roughness = Basic Mays Road Meter in/mi. Roughness +1.5(50-S), where S = speed in mph.

8. The best speeds for operating either the PCA Road Meter or the Mays Road Meter are 40 and 50 mph.

9. The Mays Road Meter should not be operated at 60 mph because of lack of reliability of the speed correction equation at that speed.

10. Both the PCA Road Meter and the Mays Road Meter are relatively inexpensive, with the cost of obtaining and installing probably less than $1,000.

11. The PCA Road Meter and the Mays Road Meter utilize an ordinary sedan without a trailer and at speeds resembling normal highway speeds, 40 or 50 mph.

12. The BPR Roughometer requires a trailer, is more costly and operates at a somewhat slower speed of 20 mph.

RECOMMENDATIONS

1. The Louisiana Department of Highways should purchase a Mays Road Meter and operate their present PCA Road Meter and the Mays Road Meter in the same vehicle, preferably an automobile.

2. All present roughness testing devices should be retained for specialized uses or for emergency status.

3. The Mays Road Meter should be used as the principal roughness measuring device, the PCA Road Meter should be used as the principal serviceability index gathering device and these two devices should be used simultaneously in order to compare results.

4. The PCA Road Meter and the Mays Road Meter should be operated at a basic speed of 50 mph during testing.

5. Consideration should be given to placing either a PCA Road Meter or a Mays Road Meter in each of the nine districts of the state for use in new construction or maintenance. The authors recommend using the Mays Road Meter for this purpose. These units should be calibrated periodically using established test courses.

6. Additional work should be done from time to time on refining these correlations and correction equations and reviewing any new significant contributions from other sources concerning roughness measuring devices.

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APPENDIX

TABLE 4
ROUGHNESS CORRELATION DATA

Variables		All Points PCC	Good Points PCC	All Points HM	Good Points HM	All Points ST	Good Points ST	All Points HM & ST	Good Points HM & ST	All Points PCC, HM & ST	Good Points PCC, HM & ST
PCA Car	R^2	0.826	0.870	0.824	0.883	0.940	0.677	0.912	0.817	0.868	0.842
vs	b	0.486	0.539	0.700	0.957	0.745	0.357	0.714	0.832	0.623	0.619
PCA Sta. Wg.	a	13.75	12.22	7.23	4.17	3.51	14.82	6.32	5.62	8.67	9.47
PCA Car	R^2	0.765	0.645	0.888	0.898	0.967	0.893	0.932	0.895	0.888	0.870
vs	b	0.268	0.185	0.263	0.268	0.355	0.241	0.319	0.259	0.302	0.236
Mays Meter	a	-7.34	2.76	-7.19	-7.33	-17.69	-5.38	-12.95	-6.82	-11.45	-4.45
PCA Car	R^2	0.662	0.797	0.572	0.841	0.924	0.586	0.694	0.684	0.583	0.579
vs	b	-19.280	-19.625	-19.026	-22.035	-47.900	-16.417	-27.590	-17.270	-22.852	-16.281
PSR (Rating)	a	91.15	91.81	79.55	92.39	150.98	67.86	104.69	74.98	95.46	75.68
PCA Car	R^2	0.526	0.787	0.694	0.779	0.450	0.085	0.437	0.733	0.420	0.696
vs	b	0.350	0.279	0.257	0.315	0.965	0.214	0.328	0.273	0.324	0.277
BPR Rough.	a	-12.37	-6.80	-9.85	-15.86	-121.15	-6.13	-18.29	-12.13	-14.34	-10.10
Mays Meter	R^2	0.810	0.938	0.814	0.899	0.970	0.998	0.905	0.947	0.865	0.932
vs	b	1.568	2.757	2.497	3.334	2.097	2.104	2.153	2.260	1.942	2.362
PCA Sta. Wg.	a	87.65	58.95	58.20	44.12	59.82	67.48	62.65	61.42	70.37	63.50
Mays Meter	R^2	0.855	0.808	0.487	0.773	0.957	0.954	0.682	0.792	0.609	0.693
vs	b	-71.400	-72.001	-63.007	-78.136	-135.140	-134.281	-82.810	-86.494	-72.925	-72.854
PSR (Rating)	a	365.67	366.45	301.18	358.62	475.67	474.17	358.18	376.39	345.93	350.57
Mays Meter	R^2	0.864	0.920	0.679	0.876	0.533	0.185	0.515	0.833	0.534	0.768
vs	b	1.461	1.334	0.913	1.224	2.914	1.177	1.077	1.081	1.141	1.183
BPR Rough.	a	-38.63	-28.09	-2.28	-39.03	-322.80	-48.91	-23.27	-24.82	-18.30	-25.30
PCA Sta. Wg.	R^2	0.626	0.723	0.510	0.803	0.922	0.923	0.697	0.736	0.576	0.616
vs	b	-35.090	-44.654	-23.297	-19.131	-62.304	-62.148	-36.994	-35.783	-33.940	-35.411
PSR (Rating)	a	145.21	177.08	91.34	78.91	193.12	192.25	133.02	130.66	131.20	137.96
PCA Sta. Wg.	R^2	0.560	0.931	0.684	0.867	0.461	0.850	0.461	0.645	0.437	0.670
vs	b	0.675	0.461	0.331	0.404	1.272	2.170	0.451	0.681	0.494	0.598
BPR Rough.	a	-48.03	-29.26	-20.09	-26.97	-163.53	-297.92	-33.35	-55.64	-33.54	-45.86
PSR (Rating)	R^2	0.818	0.791	0.533	0.846	0.517	0.006	0.585	0.833	0.644	0.814
vs	b	-0.018	-0.016	-0.009	-0.014	-0.021	0.003	-0.011	-0.014	-0.013	-0.015
BPR Rough.	a	5.40	5.12	4.15	4.80	5.77	2.12	4.40	4.85	4.70	4.99

Basic Equation, $y = a + bx$

TABLE 5

COMPARISON OF COEFFICIENTS OF DETERMINATION, R^2

Variables	All Points - 50 mph					Good Points - 50 mph				
	PCC	HM	ST	Flex.	Total	PCC	HM	ST	Flex.	Total
PCA Car - $\sum(D)^2$ vs. PCA Sta. Wg. $\sum(D)^2$	0.826	0.824	0.940	0.912	0.868	0.870	0.883	0.677	0.817	0.842
PCA Car - $\sum(D)^2$ vs. Mays Meter, in/mi.	0.765	0.888	0.967	0.932	0.888	0.645	0.898	0.893	0.895	0.870
PCA Car - $\sum(D)^2$ vs. PSR (Rating)	0.662	0.572	0.924	0.694	0.583	0.797	0.841	0.586	0.684	0.579
PCA Car - $\sum(D)^2$ vs. BPR Rough., in/mi	0.526	0.694	0.450	0.437	0.420	0.787	0.779	0.085	0.733	0.696
Mays Meter in/mi. vs. PCA Sta. Wg. $\sum(D)^2$	0.810	0.814	0.970	0.905	0.865	0.938	0.899	0.998	0.947	0.932
Mays Meter in/mi. vs. PSR (Rating)	0.855	0.487	0.957	0.682	0.609	0.808	0.773	0.954	0.792	0.693
Mays Meter in/mi. vs. BPR Rough., in/mi	0.864	0.679	0.533	0.515	0.534	0.920	0.876	0.185	0.833	0.768
PCA Sta. Wg. $\sum(D)^2$ vs. PSR (Rating)	0.626	0.510	0.922	0.697	0.576	0.723	0.803	0.923	0.736	0.616
PCA Sta. Wg. $\sum(D)^2$ vs. BPR Rough., in/mi	0.560	0.684	0.461	0.461	0.437	0.931	0.867	0.850	0.645	0.670
PSR (Rating) vs. BPR Rough., in/mi	0.818	0.533	0.517	0.585	0.644	0.791	0.846	0.006	0.833	0.814

Average R^2 for Roughness Equations Involving Following Equipment

All Points		Good Points	
PCA Car	- 0.739	PCA Car	-0.743
PCA Station Wagon	- 0.734	PCA Station Wagon	-0.828
Mays Meter	- 0.776	Mays Meter	-0.825
BPR Roughness	- 0.568	BPR Roughness	-0.696
Method - PSR (Rating	- 0.673	Method - PSR (Rating)	-0.730

Figure 10

Temperature Correction Curves and Equations

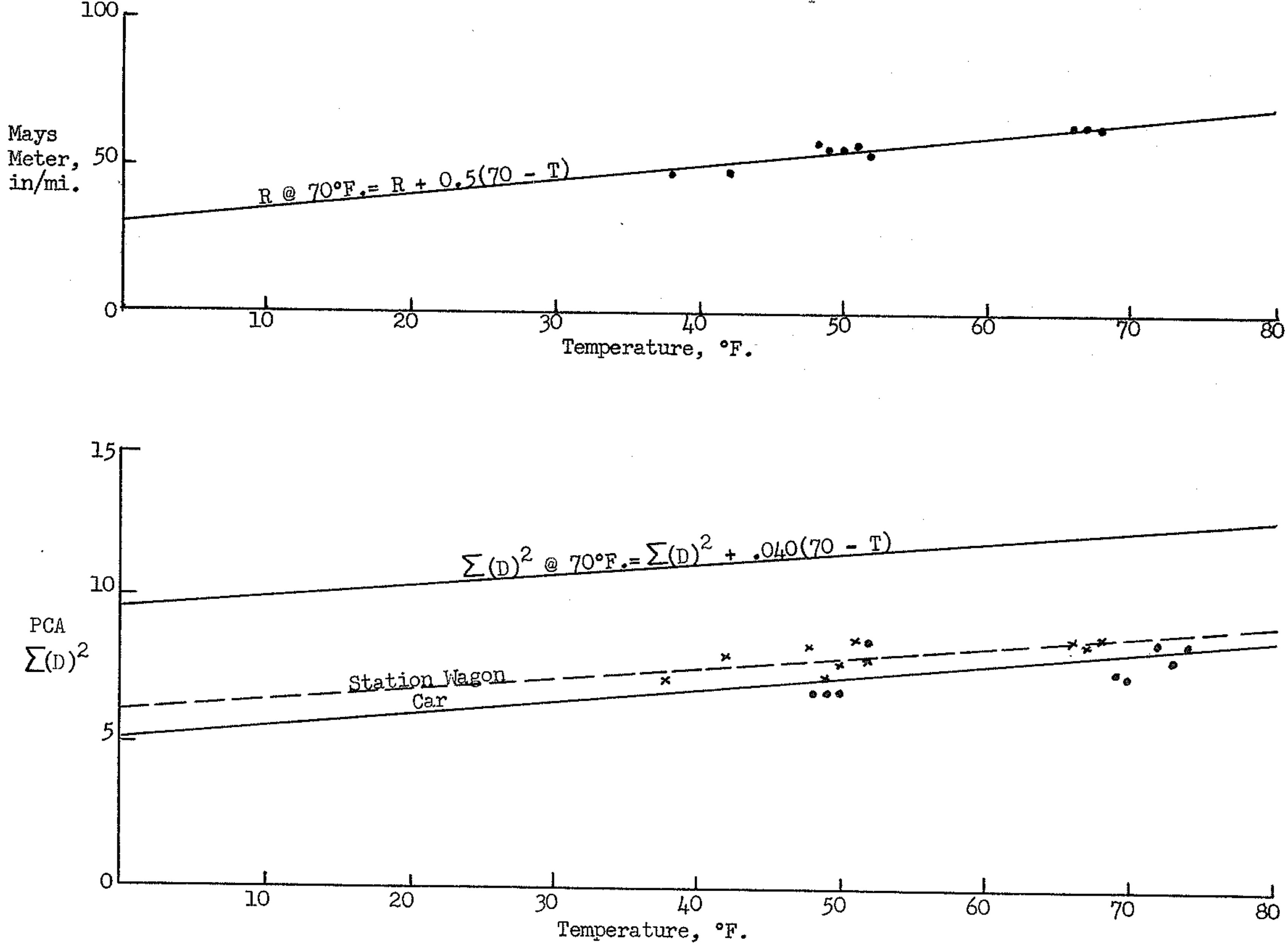

Figure 11

Curves Showing $\sum(D)^2$ Results from PCA Road Meter for Speed Changes