A CORRELATION STUDY OF THE MAYS ROAD METER WITH THE SURFACE DYNAMICS PROFILOMETER

by

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PREFACE

This is the first report presenting results from Research Project 3-8-71-156, "Surface Dynamics Road Profilometer Applications." The project was initiated to carry out the implementation and operation of the Surface Dynamics (SD) Road Profilometer in field and research applications.

The SD Profilometer measuring system was initially developed under Research Project 3-8-63-73, "Development of a System for High-Speed Measurement of Pavement Roughness." A set of serviceability index (SI) prediction equations was also developed during that project from the results of a large-scale rating session of typical Texas pavements. The current project involved the implementation of many of the research results from project 3-8-63-73. The assistance of Texas Highway Department Contact Representative Jim Brown is especially appreciated. The assistance of project personnel Pat Machalek and Dennis Banks should also be acknowledged.

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LIST OF REPORTS

Report No. 156-1, "A Correlation Study of the Mays Road Meter with the Surface Dynamics Profilometer," by Roger S. Walker and W. Ronald Hudson, discusses a study of the correlation between measurements made with the Mays Road Meter and the Surface Dynamics Profilometer and, based on this study, provides a set of calibration, operation, and control procedures for operation of the Mays Road Meter using serviceability index values from the profilometer as a measurement standard.

ABSTRACT

A correlation study of roughness measurements obtained with the Mays Road Meter (MRM) and the Surface Dynamics Profilometer (SDP) has been made and is reported herein. In accordance with information obtained from this study, a tentative set of calibration, operation, and control procedures has been developed for the MRM to provide a means of obtaining roughness measurements for Texas highways in terms of serviceability index. Several MRM's which have been calibrated and for which the results have been reported according to these procedures are currently in field use by the Texas Highway Department.

KEY WORDS: Surface Dynamics Profilometer, Mays Road Meter, serviceability index.

SUMMARY

The problem of providing an objective tool for determining when a pavement has failed has yet to be solved completely. However, development of the pavement serviceability performance concept by Carey and Irick during the AASHO Road Test standardized a performance measurement procedure with which efforts toward solving this problem might better be directed.

The Mays Road Meter (MRM) has been found to be an effective, inexpensive device for measuring road roughness, but MRM roughness measurements are dependent on all factors which affect the mass and suspension system of the vehicle used with the MRM and these factors vary from vehicle to vehicle. Therefore, standard roughness measurement values are needed for calibration.

By use of the Surface Dynamics Profilometer (SDP) serviceability index (SI) values as a standard, a correlation study of these two devices was made and a general set of calibration, operation, and control procedures was developed for MRM's purchased by the Texas Highway Department. The calibration, operation, and control procedures provide a means of reporting roughness in terms of standard roughness values for all MRM's, thus enabling different devices to give the same roughness readings for the same road section. Several MRM's have been calibrated according to these procedures and are currently in use.

IMPLEMENTATION STATEMENT

A general set of calibration, operation, and control procedures has been developed for the Mays Road Meter (MRM) using the serviceability index values from the Surface Dynamics Profilometer (SDP) as the measurement standard. Several MRM's have been calibrated according to these procedures and are currently being used in field operations. With these procedures, MRM's which are purchased by the various THD districts can be used for riding quality measurements in terms of standard values.

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CHAPTER 1. INTRODUCTION

During the latter part of Project 3-8-63-73, "Development of a System for High-Speed Measurement of Pavement Roughness," a pilot study was conducted in which roughness measurements of pavement sections obtained with the Mays Road Meter (MRM) were compared with serviceability index (SI) values of the same sections obtained with the Surface Dynamics Profilometer (SDP) (Ref 1). The results of this study indicated that the roughness statistics obtained from these two devices were highly correlated. Subsequent trials of the MRM provided increased confidence in the use of this device for roughness measurements. Consequently, one of the proposed tasks for Project 3-8-71-156 was to provide a more extensive comparison between these devices and develop a procedure for the calibration, operation, and control of the MRM using SI computations from SDP data as the standard. This report summarizes the results of this task.

The Need for SI Measurements

The problem of determining when a pavement has failed has yet to be solved. However, the development of the pavement serviceability performance concept by Carey and Irick (Ref 2) during the planning of the AASHO Road Test was an attempt to standardize a performance measurement procedure with which efforts toward solving this problem might better be directed. This concept was accepted and used in research conducted by Project 3-8-63-73, and a set of SI prediction equations or models was developed around slope variance computations of road profile data obtained with the SDP (Refs 1 and 3). By using such models, a standardized performance measurement procedure for Texas highways was established. The resulting values are useful inputs to many different projects, such as determining maintenance schedules and studying the effects of various environmental conditions on pavement.

The SDP has proven to be a good device for obtaining accurate road profile information. However, because of its high equipment investment and operating cost and the desirability of having a simple economical device available, it was decided to investigate the Mays Road Meter (MRM). This device, however, unlike the SDP, is extremely sensitive to the vehicle in which it is installed as well as to environmental and other conditions. Therefore, to be useful for providing roughness measurements, these devices have to be calibrated to some standard and then continually controlled to insure accuracy. The SDP is a standard measuring device which can be used for calibration but a well-defined procedure for checking the MRM is needed. Such a calibration procedure is described herein.

Initial Mays Road Meter - SD Profilometer Correlations

In the initial MRM-SDP correlation study, a 1969 Ford was used to house the MRM device (Ref 1). An experiment was conducted in which two sets of repeat runs over 15 test sections were made with the MRM. The average of the two roughness measurements of each section (in inches per mile) was then correlated with the SI values obtained for these same sections with the SDP. In these comparisons, SI was regressed on the log MRM roughness readings, and Eq 1.1 was obtained:

$$SI = 2.77 - 1.99 \cdot (\log_{10} M - 1.87) \tag{1.1}$$

In this regression a standard error of 0.345 and R^2 of 0.876 was obtained. Figure 1.1 illustrates this initial correlation equation.

Subsequent runs using this model yielded reasonable results in both replication and SI. However, since this initial study was only a pilot investigation, the uses of the equation were limited. For instance, if the SI values obtained from the SDP were to be the standard, then its measurements should be the ones with less errors and, hence, the MRM readings would be the dependent variable.* Also, in addition to obtaining an adequate model, it is necessary to establish the minimum section lengths for MRM measurements. These, as well as other considerations, were recognized in the more extensive correlation studies described in this report.

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* Regression analysis assumes that the dependent variable is the only random variable. Since no engineering data are truly exact, i.e., without some error, the relative magnitudes of errors among variables must be considered.

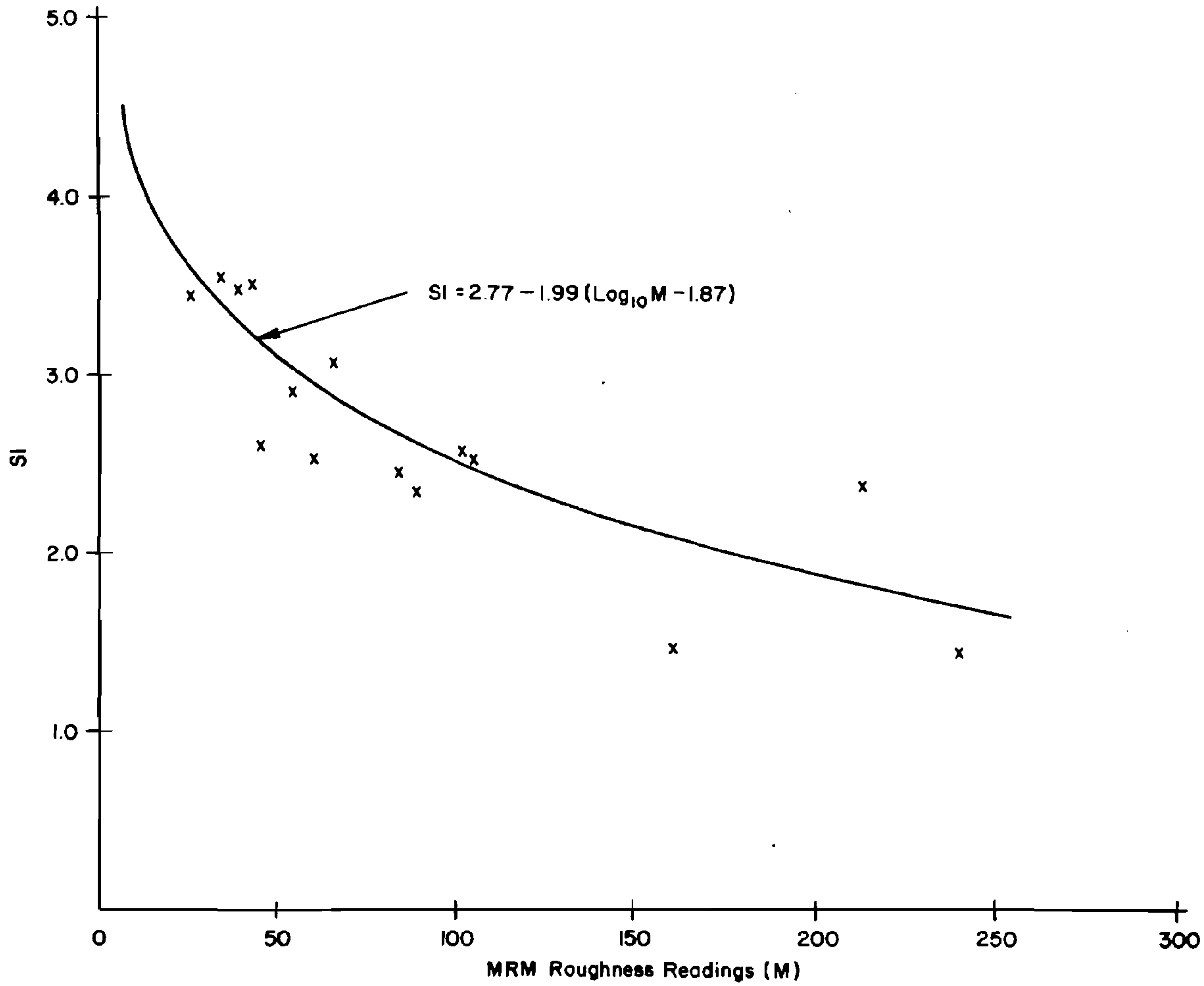

Fig 1.1. Surface Dynamics Profilometer SI versus MRM roughness.

The following chapter provides a brief description of the MRM device. Chapter 3 presents details on the experiment and results. Appendix 1 provides tentative calibration, operation, and control procedures for using the MRM to obtain SI. These procedures are written so that they can be extracted for MRM field use. Appendix 2 provides details on the Mays Ride Meter manufactured by Rainhart Engineering.

CHAPTER 2. MAYS ROAD METER

The Mays Road Meter (MRM) was initially developed in 1967 by Ivan Mays, a Texas Highway Department Senior Design Engineer, to provide a simple and operationally useful device for measuring road roughness. Texas Transportation Institute, Texas A&M University (Ref 4), subsequently confirmed the usefulness of this device as a roughness measuring instrument. In fact, when compared with the BPR Roughometer, the PCA Roadmeter, and the CHLOE Profilometer, the MRM was recommended as the most appropriate of these devices for general field use. The Louisiana Highway Department (Ref 5) also evaluated the MRM and found it preferable to other existing roughness measuring devices. The primary advantages of the MRM have appeared to be its ease of operation and the roughness record provided concomitantly with the roughness measurements, which gives a permanent record of the locations of particular rough areas in a pavement. It is not the purposes of this report to evaluate or compare the MRM with other roughness measuring devices, but to correlate measurements with this device with the serviceability index values of the SDP. However, following a brief discussion of the general operating characteristics of the MRM, the reasons for selecting the MRM for this study are indicated.

Measuring Technique

The general measuring technique of the MRM is similar to that of the BPR and PCA devices. That is, roughness measurements are proportional to the vertical changes between the vehicle body and its rear axle as the vehicle travels over a pavement. These vertical motions are accumulated and are recorded on an advancing paper tape or strip chart by a recording pen simultaneously moving at a rate proportional to the movements of the vehicle body and its differential. Vehicle distance traveled is also indicated on the roughness chart by an automatic event marker connected to the speedometer drive system. By measuring the amount of chart movement per unit of road length traveled, a roughness measurement directly proportional to the total body-differential movement, in inches per mile, can be obtained. The roughness pattern or signature permanently recorded on the paper tape provides additional information for indicating where particular rough areas were. Thus, in addition to a roughness number or index value, the proportion the various pavement areas contribute to the overall roughness measurement is also provided. (This particular characteristic was quite useful in obtaining minimum measurement distances for SI computations. See the experiment design details of Chapter 3.) The appendix provides complete details of the measuring technique.

The initial MRM instrument employed mechanical pulleys for driving the paper chart tape and for the pen arm movements. Rainhart Engineering Company is currently manufacturing a commercial version of the device (called the Mays Ride Meter) and has replaced the pulleys with a photocell sensing system, which drives a stepping motor for pen and chart drive movements. The Rainhart version is operationally much more convenient and has been found to be more accurate. The recording device of the Rainhart version, for instance, can be placed in the operator's lap and additional notes can be transcribed on the chart paper while the machine is in operation. Figure 2.1 depicts a typical paper tape measurement record of the Rainhart MRM. As noted in this figure, for this device 1/20-mile distance markers provide the distance reference for the roughness measurements. An additional event marker is supplied for further record identification.

Why Mays Road Meter

The need for an immediate SI measurement has been detailed in Refs 1 and 6. The MRM was available, and because of its favorable characteristics, as indicated in a Texas Transportation Institute (TTI) study, it was selected for a pilot correlation study, as earlier indicated.

Probably the only other instruments which would compare economically with the MRM are the PCA and BPR devices. All three measure roughness indirectly by measuring vehicle body motion, and are obviously correlated for the typical road section with slope variance, roughness index, profile wavelengths, vehicle shock absorbers, vehicle type, body weight, etc. None measures roughness characteristics directly. The PCA meter, which is sometimes incorrectly termed a slope variance measuring device, does provide an estimate of slope variance by correlation equations, but it obviously does not measure slope variance directly. This fact is easily demonstrated by measuring an imaginary

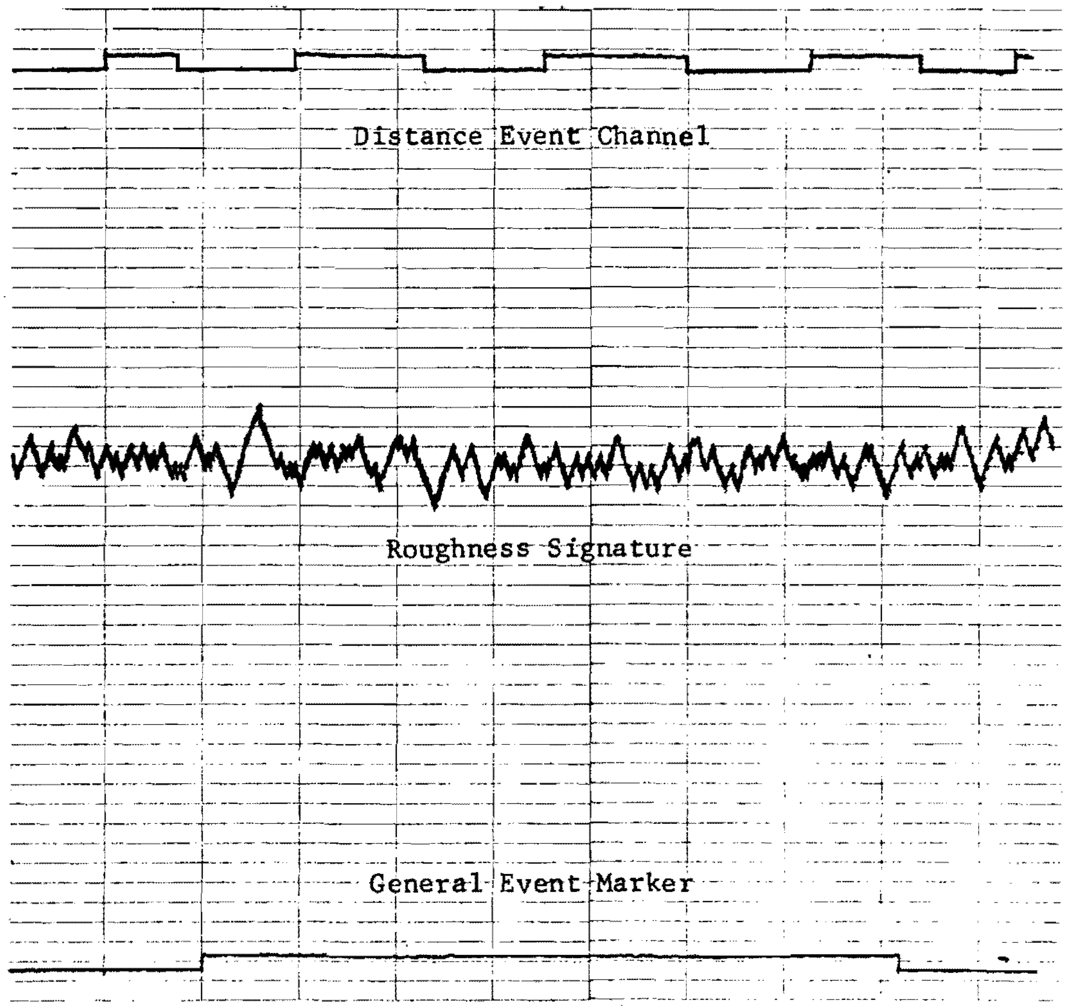

Fig 2.1. Typical Rainhart MRM measurement record.

road which has a profile in the form of a sine wave with a period that is an integer multiple of the base length used in the slope variance calculation. For such a road, the slope variance is, of course, identically zero; however, there will be body motion of the car if the amplitude of the wave is great enough.

All the devices examined are considered equally undesirable for accurate roughness measurements in comparison with the SDP. The MRM, however, was found to be the most convenient and hence was selected. The following chapter provides details on the SDP-SI and MRM measurements correlation study.

CHAPTER 3. CORRELATION STUDIES

As indicated in Chapter 1, a pilot study comparing SDP-SI values with MRM roughness measurements revealed certain similarities between these two devices. Because of this initial study, the need for extensive SI measurements on Texas pavements, and the MRM cost and operational advantages, it was decided to more completely investigate the correlation between these two devices. Once an acceptable correlation model could be found, then a general procedure for calibrating MRM devices to the SDP-SI measurements could be developed.* This chapter provides the description and results of the model development phase of this study. The calibration procedure described in Appendix 1 uses this same experimental design in obtaining the SDP-MRM calibration model. The SI models used for the correlations are direct functions of road profile wave amplitudes rather than slope variance, patching and cracking, etc. Initially, the slope variance models were employed in the experiment; however, as the experiment progressed, a new SI prediction equation was developed which predicted SI entirely as a function of road profile wave amplitudes. Details of this model will be provided in the final report on Research Project 156.

Experiment Design

The primary function of the experiment design is to

(1) determine an adequate correlation model which can be used for predicting SI for the MRM; and

(2) given this model, determine the general operational requirements of the model, such as minimum section length and replication.

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* In order to prevent confusion, the differences between the terms correlation and calibration will be given for this report. Correlation consists of determining how well MRM values can be related to SDP-SI values. The equation which relates these two variables is referred to as the correlation equation or correlation model. Calibration is the process of correlating each specific MRM in accordance with this correlation model.

For the experiment, both the old mechanical type MRM built by the Texas Highway Department and the electronic controlled Rainhart manufactured device were used. Initial studies were to include only the former; however, during the study, Project 1-8-69-123, "A System Analysis of Pavement Design and Research Implementation," purchased a Rainhart manufactured meter and it was included in the experiment in order to increase the sample size for statistical purposes and to provide Project 123 with a calibrated MRM for project work.* The study results are primarily oriented toward the Rainhart MRM, since, first, it appears to have both an accuracy and operational advantage over the mechanical device, and, second, it is commercially manufactured and hence is likely to receive more widespread usage than the other meter.

Both devices provide distance events at 1/20-mile resolution; thus, replication and/or minimum distance requirements will be integer multiples of these 1/20-mile events. With this resolution stipulation, the following experiment was designed.

Twenty-three 1/4-mile test sections considered representative of the pavement roughness range for Texas pavements were selected. Another criterion for selection was that each section have relatively homogeneous roughness characteristics throughout the 1/4-mile test section.** Four replication runs were made with the MRM over each section; the sections were also measured with the SDP and their respective SI values were computed. Because of the requirement of item 2 above, to determine minimum section length and replication requirements, each MRM section run was divided into five 1/20-mile segments, thus providing a total of 20 sample segments per section. The overall experimental design is illustrated in the flow chart of Fig 3.1. The section segmenting is indicated by item 1 of this figure. Assuming any single segment provides an unbiased estimate of the SI (because of the assumed homogeneous roughness characteristic

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* Since the initial correlation experiment, several additional MRM's (Rainhart version) have been calibrated according to the procedures specified in this chapter.

**The relatively homogeneous roughness was judged in the same manner as in the original SI rating session of Ref 3, i.e., it had to be constant from the standpoint of typical pavement characteristics.

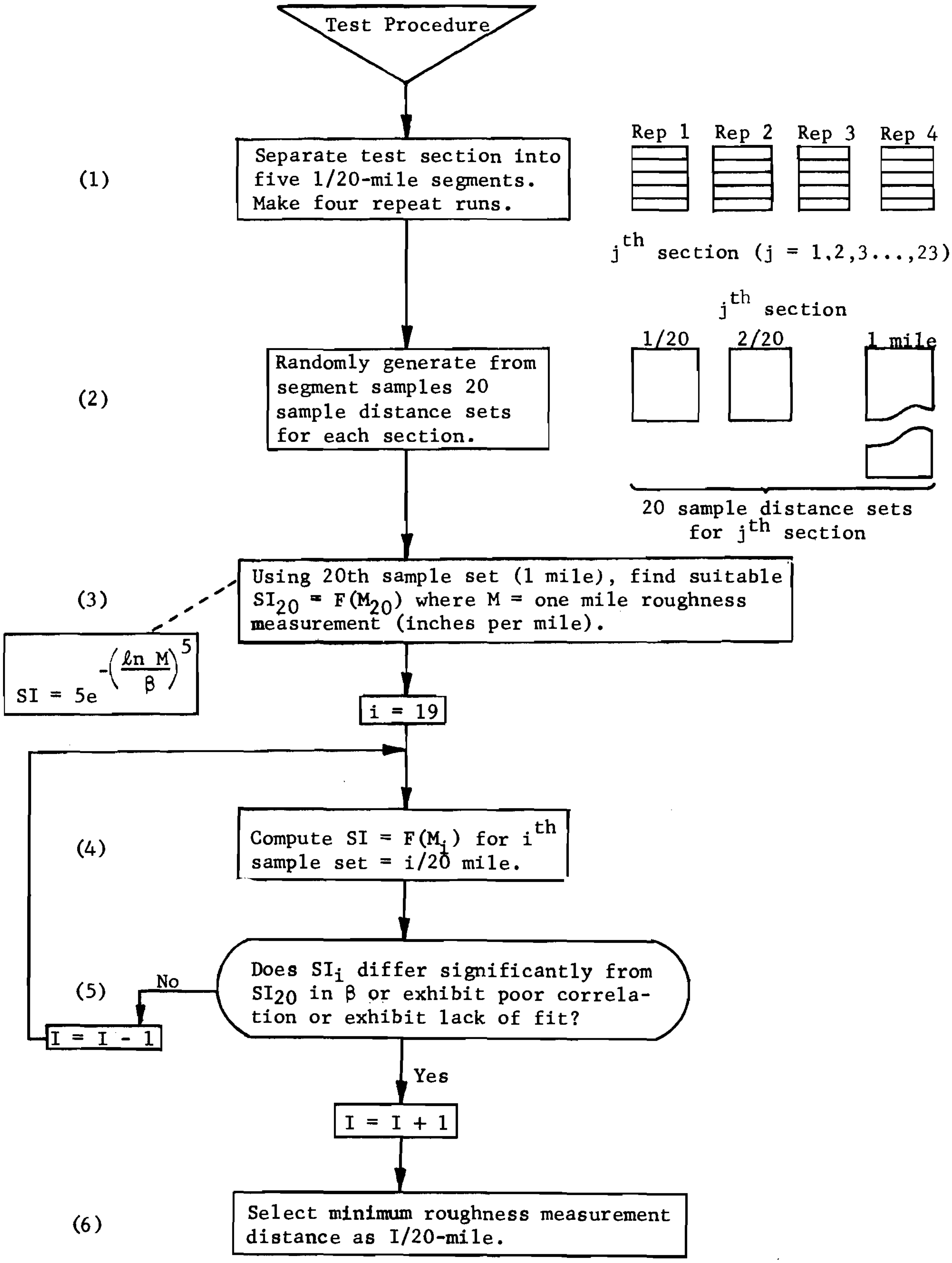

Fig 3.1. MRM-SDP correlation experiment.

of each section), 20 sample segment sets were generated. The first set consisted of one 1/20-mile sample segment drawn randomly from each of the 20 possible samples for each of the 23 sections. The second sample set contained two such 1/20-mile randomly selected sample segments, etc., up to and including a twentieth sample segment. Thus, the n sample sets correspond to n/20-mile MRM measurements, and n varies from 1 to 20 (see item 2 of Fig 3.1).

Since the twentieth sample set contains the most degrees of freedom, that is, provides the best roughness estimates for correlating to the SDP-SI measurements, these data were used in the search for a suitable model for correlation between the SDP and MRM. After a considerable amount of effort, the following model was found to adequately represent or predict SI based on MRM roughness measurements:

$$SI = 5e^{-\left(\frac{\ln M}{\beta}\right)^5} \tag{3.1}$$

where

M = MRM roughness measurement, in inches per mile, $M \geq 1$;

β = MRM instrument coefficient (5.697 for the sample 20 set for the electronic Texas Highway Department MRM).

This equation was obtained by linearly regressing M on SI and then solving for SI. The procedure for finding a suitable model for the sample 20 data set is depicted in item 3 of the experiment test procedure flow chart (Fig 3.1).

Once an acceptable model is found, how adequately this model functions for the other smaller sample segment sets must be determined. That is, it is necessary to find the minimum sample set or section length which can be used for adequate SI prediction measurements. To meet this minimum distance requirement, models for each of the other sample sets are generated and compared with the sample 20 model by first statistically comparing the β differences and then examining the lack of fit of the sample 20 model using the other sample segment sets. As shown in items 4 and 5 of Fig 3.1, this model testing procedure begins with the nineteenth sample segment set and continues in decreasing distance order until a model is found which is significantly different or inadequate. The sample segment set at which this occurs thus represents the minimum required MRM segment distance and furthermore, since these segments are randomly selected, it also indicates the replication requirements. For example, it was found that the mechanical MRM should include at least three 1/20-mile distance segments for adequate SI predictions. This means that either a 1/20-mile section length must be run three times and the sum of these three measurements used, or a 3/20-mile section can be used, which requires only one run.

Data Collection and Processing. As indicated in Fig 3.1, the data collection phase involved running both the MRM and SDP over 23 test sections and obtaining the appropriate roughness measurements for each section. The MRM data runs consisted of four replicate runs, as discussed earlier. The roughness measurements were taken directly from the MRM roughness records. The SI values for each SDP profile run, however, could not be computed until the profile data were digitized and the power or variance spectrum computed. The SI values were then computed directly from the power or variance spectral estimates after they were transformed to wave amplitudes.

A typical MRM roughness record (Fig 2.1) provides three information channels, a distance marker (indicating 1/20-mile distance traveled increments), a vehicle body deflection measurement, and a general event marker used by the operator for signaling certain measuring events, such as the start or end of a particular test section. For the twenty 1/20-mile sections for each 1/4-mile section, each 1/20-mile distance mark is measured in inches and recorded from the first channel of the roughness record. The distance measurements may then be converted to actual vehicle body deflection measurements per one-mile section by multiplying each by 20 times the MRM measurement vehicle differential ratio (6.4 for the Rainhart manufactured device).

Data Analysis

The data analysis phase consists of finding an adequate SI model for the twentieth sample segment and then determining the model's minimum section length constraint. Since regression analysis would be used for obtaining this model and the dependent variable is to be the MRM roughness measurement (i.e., the greatest errors are assumed to exist in the MRM roughness readings, or the SDP-SI computations are more stable), the MRM readings were then examined for homogeneous variance characteristics. Plots of the coefficient of variation of the MRM roughness readings revealed a somewhat constant relationship for the different roughness readings. Such a relationship suggests the use of the log transformation on this variable (see Ref 7), in order to insure the homogeneous roughness assumptions in the regression analysis.

As indicated in the previous section, the search for a suitable model to show correlation between the SDP and MRM involved using the data from the twentieth sample set, since this set provided the best roughness estimates (i.e., it contained 20 independent roughness estimates). The following linear regression is then performed for the following model.

$$Y = \beta X + \epsilon \tag{3.2}$$

where

$Y = \ell n \ M$;

β = linear regression coefficient;

M = Mays Road Meter accumulated roughness reading, in inches per mile;

$X = \left[\ell n(5/SI)\right]^{1/5}$;

ϵ = the residual or regression error.

The Y intercept β_0 is zero for this model since the SI is five, the MRM roughness value is at its minimum, which is to be assumed one.*

Equation 3.1 can be obtained from Eq 3.2 by solving for SI in terms of M . Figure 3.2 provides a plot of the sample 20 data set using the sample 20 model.

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* Since M typically will always be greater than one, it was assumed that the minimum M is one rather than zero. The SI of five is a boundary condition and is typically never reached; thus, the selection of one rather than zero is used primarily for convenience.

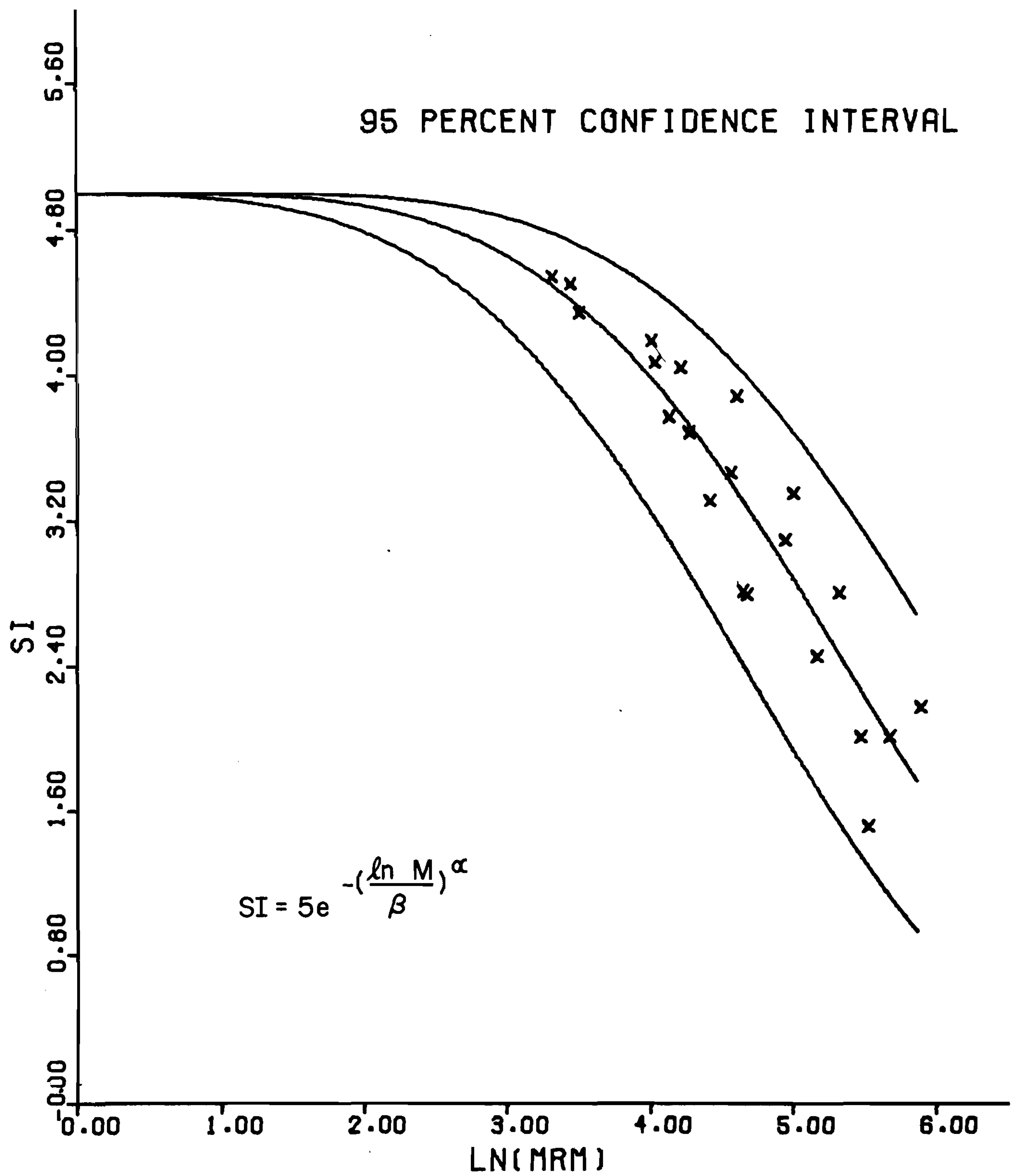

Fig 3.2. SDP-SI values versus log Mays road roughness readings.

As discussed in the experimental design section, the adequacy of the sample 20 model for the smaller sample segment sets establishes the minimum MRM resolution constraints. To meet this minimum distance requirement, the following tests were performed on each sample segment model as indicated in items 4 and 5 of Fig 3.1.

(1) Tests for similarity in models - Perform a Student's t-test on each β_i , $i = 1,19$, where β_i is the linear regression coefficient for the i^{th} sample segment. This test indicates statistically if the two β terms can be considered from the same population. The statistical test used is as follows:

$$t = \frac{\beta_{20} - \beta_i}{\left\{v\left[\beta_{20}\right] + v\left[\beta_i\right]\right\}^{1/2}} \tag{3.3}$$

where

β_{20} = linear regression coefficient for twentieth model,

$v\left[\beta_{20}\right]$ = variance of linear regression coefficient for twentieth model,

β_i = linear regression coefficient for i^{th} model,

$v\left[\beta_i\right]$ = variance of linear regression coefficient for i^{th} model.

(2) Tests to determine the adequacy of i^{th} model - Perform an F-test on the pure error of MRM roughness and the regression residual of i^{th} model. This test determines if any lack of fit exists for the i^{th} model. The statistical test used is as follows:

$$F = \frac{(\epsilon^2)^i}{\sigma^2} \tag{3.4}$$

where

$(\epsilon^2)^i$ = the regression residual mean square of the i^{th} model;

σ^2 = the pure error variance.

Table 3.1 provides the results of these tests for the Rainhart MRM used in Project 123. As noted from this table, the sample 20 model for the Rainhart device can be used without significant error down to 1/20 of a mile resolution. However, it was found that the THD device should be used on sections of no less than 0.2-mile total length. As a further precaution and for consistency in the calibration procedures of Chapter 4, it is recommended that neither device be used on sections of less than 0.2-mile unless replication is provided.

Figure 3.2 illustrates the model 20 regression equation and the 95 percent confidence bands. The confidence bands shown in this figure are for the original regression; i.e., these bands are based on the β variance and standard error of regression, with ℓn M as the dependent variable. The confidence bands can be computed for the inverse regression, i.e., SI as the dependent variable, by the following equation (Ref 8):

$$SI_L = \frac{SI \pm \frac{t\epsilon}{\beta}\sqrt{\left(1 + \frac{SI^2}{t'_{11}} - g'\right)}}{1 - g'} \tag{3.5}$$

where

$$g' = \frac{t^2\epsilon^2}{\beta_1^2 t_{11}},$$

β = regression coefficient,

t = "t"-table value for desired confidence level,

ϵ = standard error of regression

t'_{11} = the uncorrected sum of squares of SI.

Figure 3.3 illustrates this curve when the MRM roughness values are used directly and a one standard error confidence band is used. For the sample 20 set, however, little difference could be found between these two curves for the same data and confidence band.

TABLE 3.1. MODEL TESTS FOR ACCEPTABILITY

Sample Set	Test on β_i, "t"-Value	Test for Lack of Fit, "F"-Value
1	-1.044	1.150
2	0.298	1.189
3	-0.354	0.853
4	-0.155	0.977
5	0.366	0.933
6	-0.194	0.920
7	0.058	0.884
8	0.144	1.193
9	0.269	0.885
10	-0.235	1.045
11	-0.345	0.901
12	0.090	0.866
13	-0.103	0.919
14	-0.012	0.865
15	-0.284	1.155
16	-0.198	1.055
17	-0.105	0.827
18	-0.023	1.024
19	-0.070	0.916
20	--	0.855

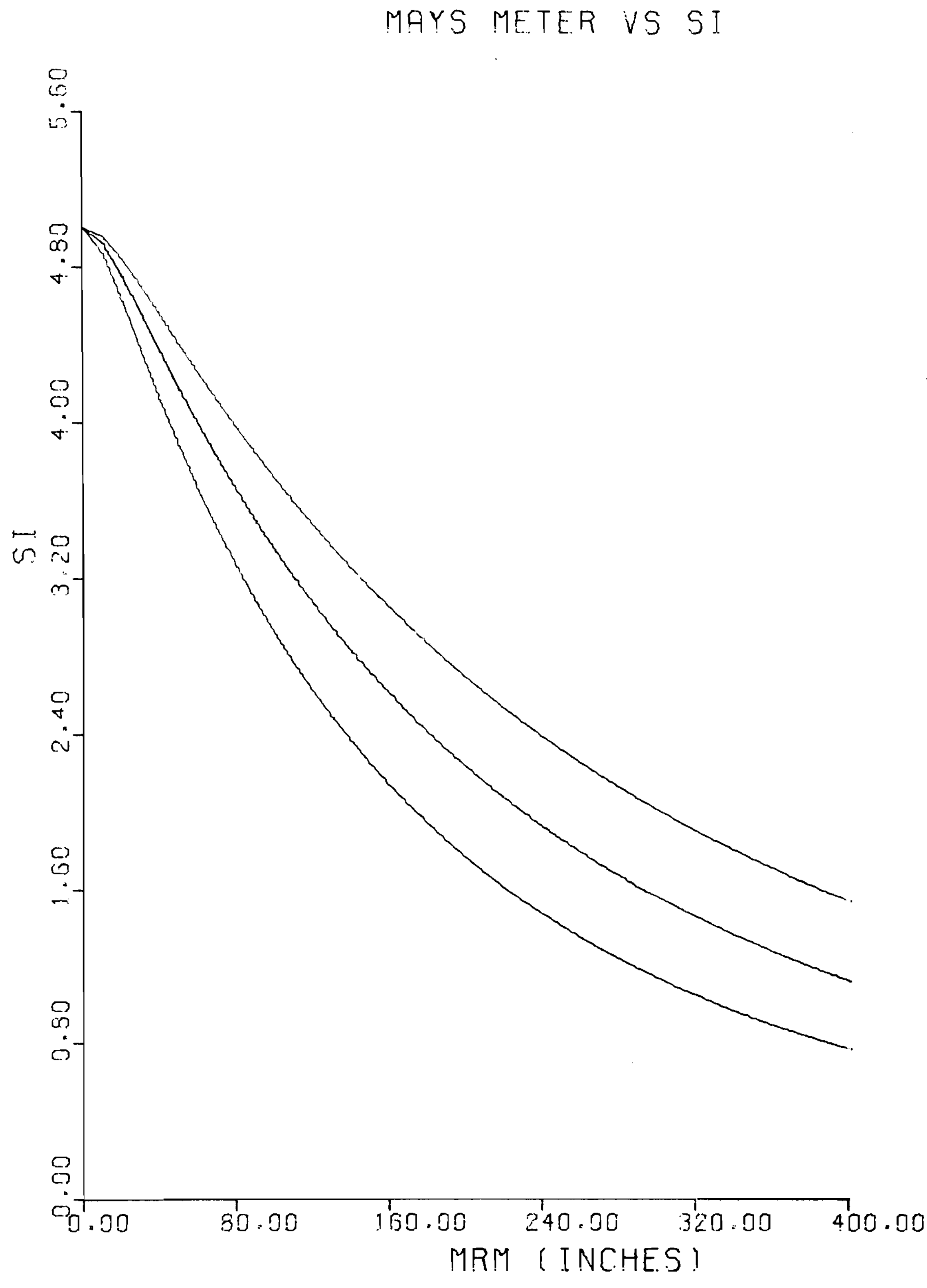

Fig 3.3. Confidence bands for inverse regression for the correlation model.

It is actually more expedient to examine the average error between the predicted and actual SI values. These errors are provided for five separate MRM's calibrated according to this model in the following section.

Calibration Results

As previously noted, the procedures described in this chapter have been used to develop a correlation model which would be useful in calibrating MRM devices. Five MRM's have been calibrated according to these procedures. The results of these calibrations are summarized in Table 3.2. Four of the devices were manufactured by Rainhart Company. The fifth is the older model THD mechanical device.

All but the device used by TTI were calibrated according to Eq 3.1. A small variation in this equation was used for the TTI calibration model in order to get a better fit. The difference could have been due to the leaf suspension system of the vehicle in which the TTI MRM instrument was mounted. In fact, it has been recommended that the MRM be operated only in a coil-spring type suspension system. Even so, with the model of Eq 3.1, there actually was no statistically significant lack of fit, primarily due to the larger replication error of the TTI device, as illustrated in Table 3.2. By examining a plot of SI versus the MRM roughness readings similar to Fig 3.2 for this device, it was observed that a better fit could be obtained by using an equation of the form

$$SI = 5e^{-\left(\frac{\ln M}{\beta}\right)^3} \tag{3.6}$$

This different model could be due to the different suspension system, as noted, or perhaps two parameters are required by the general calibration model. The appropriate general model will become more apparent only as more MRM devices are calibrated (see the note on page 22).

The Rainhart device belongs to Rainhart Company and was calibrated primarily for research reasons to see if this general curve worked well on their instrument, which was mounted in a 1963 Chevrolet stationwagon. As noted, an acceptable calibration (or, for this case, correlation) resulted.

TABLE 3.2. CALIBRATION RESULTS

Device	Replication Error*	β	SI Model Error**	R^2
File D-8	0.252	5.697	0.319	0.998
District 21	0.234	5.633	0.342	0.998
TTI***	0.424	5.192	0.292	0.994
Rainhart	0.257	5.267	0.351	0.997
Inhouse MRM	0.353	5.532	0.473	0.996

* Replication of pure error (log M , in inches per mile) used for testing lack of fit in the regression equation, Eq 3.2.

** Standard error between actual and predicted SI from Eq 3.1.

*** The model used varied from Eq 3.1 in the exponential term (see text).

NOTE: Since this report was originally prepared, several MRM's have been calibrated or recalibrated (see Appendix 1 for recalibration criteria), and it appears that the following general calibration equation should be used:

$$SI = 5e^{-\left(\frac{\ell n M}{\beta}\right)^{\alpha}} \tag{3.7}$$

For example, for some of the MRM devices installed in vehicles with heavy duty shock absorbers, the power term α was found to vary within the interval of 4 to 5. Thus, the calibration procedures have been slightly modified so as to use a nonlinear regression procedure for estimating the α and β coefficients rather than using the linear regression method described by Eq 3.2; that is, the following nonlinear model is used during regression:

$$Y = \beta X^{1/\alpha} + \epsilon \tag{3.8}$$

where Y is as defined before, α and β are the nonlinear regression coefficients, but X is now the natural log of 5/SI. Complete details on the results of the increasing use of the calibration operation and control procedures will be presented in the next project report.

CHAPTER 4. SUMMARY AND RECOMMENDATIONS

A correlation study of roughness measurements obtained with the Surface Dynamics Profilometer (SDP) and the Mays Road Meter (MRM) has been made. Based on results of this study, a set of calibration, operation, and control procedures has been developed for the MRM in order to provide a means of obtaining standard roughness measurements for Texas highways in terms of serviceability index (SI). These procedures involve correlating the MRM roughness readings, in inches per mile, with SI values based on SDP readings. Because of the SDP measurement characteristics, SI values computed from road profile data obtained with this instrument provide an accurate measurement standard.

Several MRM devices have been calibrated according to these procedures and are currently in use. Initial use of these procedures to obtain SI is quite promising, and the standard roughness measurements for roads throughout Texas which are provided are invaluable information to aid in solving the problems of pavement failure.

Because of the encouraging results of the correlation study, the development of a tentative set of procedures for the calibration, operation, and control of the MRM, and the use of these procedures in field operations, the following recommendations are made.

(1) Additional MRM's should be purchased by the various Districts and calibrated and used by these Districts for obtaining numerous measurements of pavements for maintenance and other considerations.

(2) When a sufficient number of these devices are available, further experiments can be conducted to investigate the effects of temperature, weather, tire pressure, etc.

(3) As devices are purchased and used according to the calibration, operation, and control procedures, feedback should be provided to this project so that modifications to these procedures can be made on the basis of experience gained from extensive field use.

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APPENDIX 1. MAYS ROAD METER CALIBRATION, OPERATION, AND CONTROL PROCEDURES

This appendix provides a tentative set of procedures for the calibration, operation, and control of the Mays Road Meter based on the findings in Chapter 3. This appendix has been written so that it can be extracted without modification for field use and can be made available to MRM field personnel who are not interested in the model development and project details. There is, therefore, some duplication of what is presented in other sections of this report.

MRM roughness measurements are typically obtained in inches of vertical vehicle motion per mile. Since these measurements are dependent on all factors which affect a vehicle's suspension system, and because these factors vary from vehicle to vehicle, a standard roughness value which can be used for all instruments is needed. The procedures that are described herein provide such a standard value unit. The standard value used, serviceability index (SI), is a single number ranging from zero to five, with five for a road or pavement considered perfect and zero for one considered impassable. SI values are obtained from inches-per-mile readings by use of a calibration table developed from a calibration equation. The SI values simply provide a means of correlating the roughness readings for the same section by two separate instruments.

The procedures described are divided into three areas: (1) calibration, (2) operation, and (3) control. Calibration involves developing the necessary tables for converting MRM roughness readings, in inches per mile, to SI values. The operation section indicates a standard method for measuring roughness. The control section is a method of insuring that the MRM is functioning properly. It should be noted that the control procedures described are for MRM devices in general. It should also be noted that no measuring device ever gives exactly the same measurement each time; that is, there are measurement errors. These errors can be divided into two types: actual MRM measurement errors (equipment errors) and errors due to the non-homogeneous roughness characteristics of roads.

Calibration

MRM calibration includes running roughness measurements on 25, 1/4-mile-long pavement sections, which initially are located in the Austin area, and developing the tables necessary to convert MRM roughness readings to SI values. The measurements must be made in accordance with the following specifications:

(1) MRM vehicle - The MRM must be calibrated in the vehicle in which it is to operate. Any physical characteristic (such as vehicle weight and shock absorbers) which affects vehicle body motion should be the same during calibration as in operation.

(2) Calibration sections - The 25 calibration sections have been marked by white paint stripes at the beginning and end of each test section. For scheduled calibration runs, two red flags on the right-hand side of the road and adjacent to the two white stripes aid in recognizing the test sites. A map is available to the user for locating these sections.

(3) Test operations -

  (a) Each 1/4-mile test section should be run five times. Each run should be made at 50 mph and this speed should have been reached about 0.2 mile before entering the test site and maintained for about 0.1 mile following the test site.

  (b) Only two people (a driver and an operator) should be in the vehicle during calibration, preferably the same personnel who will operate the vehicle during standard roughness measurements. If the same people are not available, then the total weight of the personnel during calibration should be about the same as the weight of personnel who will operate the vehicle.

  (c) The calibration procedure should be performed on a typical day, that is, when no extreme weather conditions exist. It is important to note that the MRM provides a measurement of vehicle body movement. Thus, any condition which might severely affect this movement should be avoided. Such factors as weather conditions and tire pressure have been found to affect MRM measurements. The effects of such variations have not yet been investigated as accurate indications cannot be obtained until empirical data are available from more than one or two MRM devices. To minimize the effects of such variations, it is recommended that the calibration measurements not be conducted under unusual environmental or vehicle conditions.

  (d) Vehicle conditions - The vehicle should be in good running order, exhibit good suspension system characteristics, be well lubricated, and have a cold tire pressure of about 31 psi (front and rear). A standard full-size vehicle is recommended, preferably one with a coil-spring suspension system.

MRM Operations

This section describes the tentative general operating procedures to be followed when obtaining roughness measurements. As indicated, these procedures are tentative and will be modified according to experience in using these devices. This section is divided into two parts. The first part explains how SI values are obtained from the MRM roughness record. Following this, the tentative operating procedures which should be followed for obtaining an accurate record are described.

SI Computation. The MRM device provides as output a 6-inch-wide strip of chart paper which contains three channels of information, as illustrated in Fig A. The purpose of each of these three channels is as follows:

(1) Distance Event Channel (upper record in Fig A) - Distance traveled by the MRM vehicle is indicated by alternate up and down 1/8-inch pen movements (pen movements in the same directions occur every 0.1-mile). This event marker is driven by the speedometer drive cable of the vehicle. Since the strip chart paper drive is a function of the vehicle body movement, the distance between successive distance marks is proportional to the cumulative vehicle body movement and hence can be scaled to inches of body movement per unit distance traveled.

(2) Roughness Signature - The strip chart paper movement is proportional to the vehicle body movement. Vehicle body movement also drives a second pen (center channel record in Fig A) across the chart, depending on the direction and magnitude of the up or down vehicle body movements with respect to the differential. Thus, this record or channel is used to indicate the pattern of vehicle body movements.

(3) General Event Marker - The third channel (lower record in Fig A) provides an up or down pen displacement when a manual event marker located on the floorboard is depressed, thus providing a means of marking specific events of interest to the driver. With the Rainhart device, the operator can also mark specific events or write notes with pencil or pen directly on the chart paper.

The MRM measurements are then made as follows:

(1) The MRM is activated and the roughness record for a desired road section obtained (see operating procedures in the following section). Figure A provides a typical example of one such section 0.2 mile long.

(2) The roughness measurement in terms of SI is obtained by first measuring the length of paper (in inches) between 0.2-mile marks on the distance event channel, as illustrated in Fig A, and then using Table A to relate this length to SI. As noted in the figure, the 0.2-mile event markers were 3.4 inches (or 3.4 X 6.4 = 21.8 inches of body movement per 0.2-mile) of strip chart movement. Table A

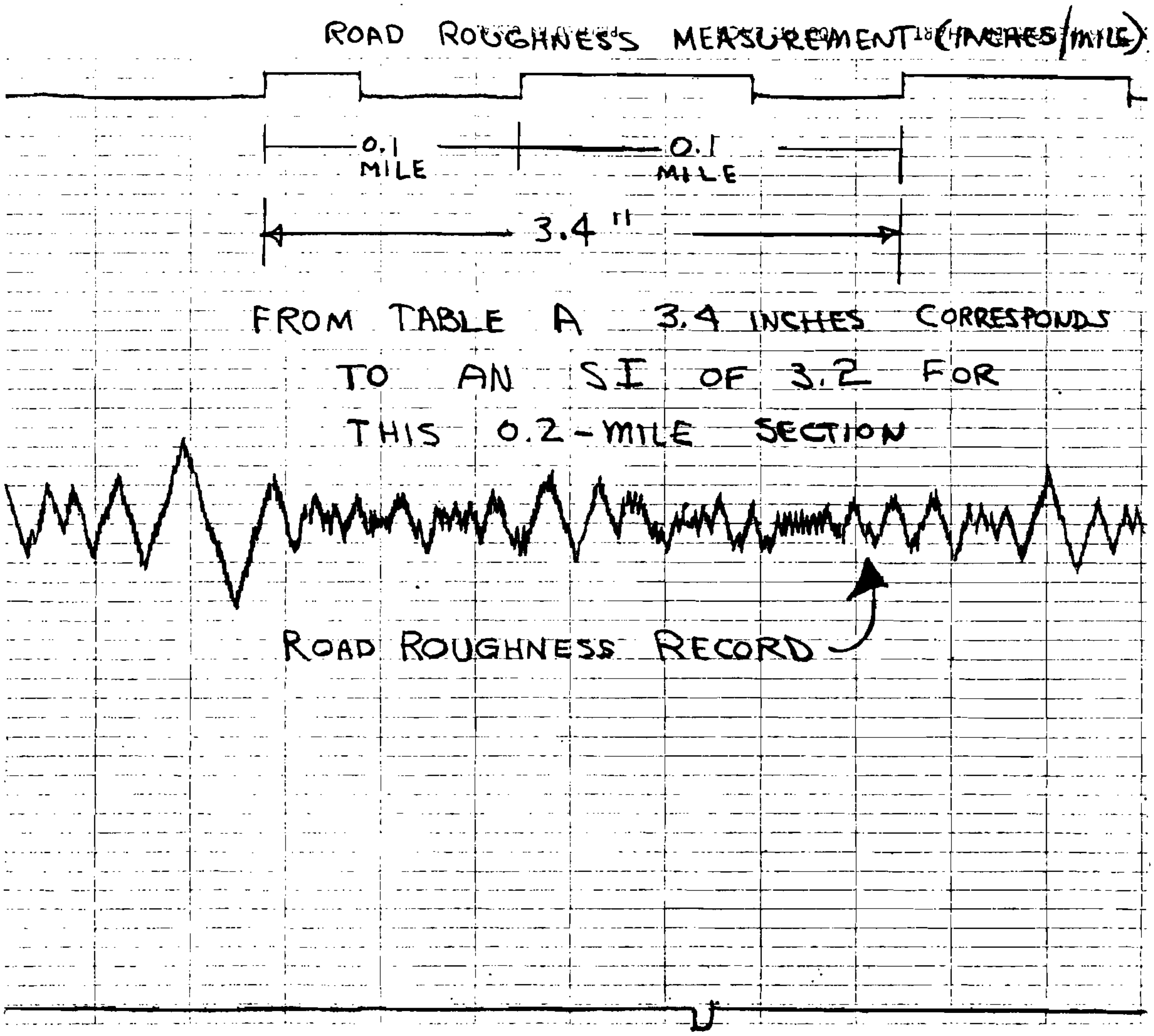


Fig A. Typical MRM road roughness measurements.

Table A. MAYS ROAD METER-SD PROFILOMETER SI CORRELATIONS

MAYS METER (IN/ .2 MI)	SI	MAYS METER (IN/ .2 MI)	SI
21.5	.50	4.5	2.80
19.4	.60	4.2	2.90
17.6	.70	3.9	3.00
16.1	.80	3.7	3.10
14.8	.90	3.5	3.20
13.7	1.00	3.2	3.30
12.7	1.10	3.0	3.40
11.9	1.20	2.8	3.50
11.1	1.30	2.6	3.60
10.4	1.40	2.4	3.70
9.7	1.50	2.2	3.80
9.1	1.60	2.1	3.90
8.6	1.70	1.9	4.00
8.1	1.80	1.7	4.10
7.6	1.90	1.5	4.20
7.2	2.00	1.4	4.30
6.8	2.10	1.2	4.40
6.4	2.20	1.1	4.50
6.0	2.30	.9	4.60
5.7	2.40	.7	4.70
5.3	2.50	.6	4.80
5.0	2.60	.4	4.90
4.7	2.70	.0	5.00

provides the relationship between body movement and SI in terms of SI intervals of 0.1; for this example, 3.4 inches of body movement corresponds approximately to an SI of 3.2. Because of the accuracies involved, the SI readings need not be read beyond one decimal place and the nearest distance interval value for the appropriate SI should be used.

MRM Tentative Operating Procedures. The operating procedures described below should be followed closely by the MRM operators in order to insure accurate readings. Variations from these procedures, such as making measurements with three people instead of two in the vehicle or with a load of cement or samples in the trunk, can significantly affect or bias the SI measurement.

The following tentative MRM operating procedures are recommended:

(1) Measurements should be made only under normal driving conditions. This particularly concerns weather. For instance, measurements should not be made during heavy rain, snow, extremely cold weather, or gusty wind conditions. There is also the possibility that abnormal tire pressure variations will affect vehicle body movement. Until more information can be obtained about such factors, measuring during any conditions which might directly or indirectly affect vehicle body movement should be avoided. The individual MRM operator can get a better understanding of these variations once the MRM control sections have been established, as described in the following section.

(2) For measuring during summer months, it is recommended that the Rainhart manufactured devices be installed in air-conditioned vehicles and that the air-conditioners be used during such time to help keep the MRM electronics cool.

(3) Before making a set of measurements, the MRM equipment should be visually inspected. The pens should be adjusted for proper marking and clearance before each measurement run.

(4) The manual event marker should be tested prior to each measurement run.

(5) Two operators are necessary, one for driving the vehicle and the second for operating the MRM. Their total weights should be approximately those (within, say, ±25 pounds) of the operators during MRM calibrations. The vehicle driver typically provides mileage information to the MRM operator and operates the event marker channel. The MRM operator monitors the roughness record, insuring proper operation, and makes any necessary event marks or comments on the strip chart during operations. When such notes are to be made, it is recommended that the recording device be kept on the operator's lap.

(6) When a test section has been selected, the MRM device should be activated and an operating speed of 50 mph* attained at least 0.2 mile before the beginning of the test section.

(7) Test section lengths have tentatively been established as 0.2 mile. Note that this length of measurement can be obtained by repeating runs on shorter segments and summing the paper output; that is, a 0.1-mile section can be run twice and the total length resulting from both runs used as the roughness distance.

Longer sections of roadway can be sampled as desired. For instance, a 20-mile length of roadway can be represented by a continuous profile of 200 0.2-mile readings or a random sample of, say, 20 measurements taken one per mile of roadway. Various statistics could be used to report these results, such as the average of 200 measurements and the standard deviation or range.

Measurement Control

Accurate measurements depend on proper usage and operation of the MRM. Proper operation of the equipment can be insured by development of a set of control procedures in which MRM results are continually monitored.

These control procedures provide a means of detecting MRM out-of-calibration (OC) conditions and involve the use of replicate runs or measurements over a known test or control section. Twenty such sections are to be established immediately following the initial MRM calibration procedures, providing a pool from which more than one control section can be selected for testing for an OC condition. The mean and range SI values from replicate control runs are then compared against known control values determined at the time the control sections were initially established.

This section describes these control procedures, which should be followed by MRM operators in order to insure proper operation of their instruments. A similar procedure would be necessary even if the roughness measurements were not to be used to get SI values, to insure proper MRM operations.

Selection of MRM Control Sections. A set of twenty 0.2-mile control sections should be selected convenient to the MRM base of operations. These

---

* Vehicle speed was set at 50 mph, as this was the speed used in developing the original SI models for the SDP. If a slower speed is desired, 20 mph should be used, although SI in this case is not necessarily correct. However, we plan to develop a model for this speed as a later research activity, at which time the appropriate SI table for this speed can be obtained.

sections should be selected so as to provide a representative sample of smooth and rough sections of the area in which the MRM is to operate. The PSR variations within each section should be homogeneous; that is, the roughness within any 1/20-mile segment of the section should be approximately the same as in any other 1/20-mile segment of the section. Obviously a smooth section with an abrupt bump at the end of the section is not a good test section. This is a relative measure and, in practice, will never be exactly met. However, as a general rule, if an experienced highway technician cannot say that any particular 1/20-mile segment of a 0.2-mile section rides any better than any other segment within the section, the section can be considered homogeneous. Since these sections are to be used for roughness control, sections where changes in the pavement conditions are expected to be minimum should be selected, so that the sections can be used as long as possible. Twenty was selected as the number of sections in order to provide a large pool from which control measurements can be made and to provide needed samples for developing the mean and range control charts. As control sections are lost, they need not be replaced as long as four sections remain. In a case where all but four or less sections are lost, the MRM should be brought back to Austin for recalibration. The selection of the control sections is an important part of the control procedures, since they will be used for determining if the MRM is still in calibration.

Establishing Control Charts. Two control charts are used for monitoring MRM measurement validity, one for checking the measurement mean (or average) from repeated SI values and the second for checking the variations from the mean of the replicate values. The two control charts are developed with measurements obtained from the 20 control sections established as described above. The range R of several MRM repeat measurements, whose mean is denoted as $\bar{X}$, is the greatest difference between SI values. This number is always a positive number, or $R = SI_{max} - SI_{min}$. To develop the two control charts, a work sheet similar to Fig B is used. To compute the control limits for these charts, each of the 20 control sections is run five times* and its SI (in terms of 0.2-mile

* Since the control limits will be computed from these initial measurements, it is important to include any run-to-run or day-to-day variations to prevent these limits from being too tight. Thus, it is recommended that each section be run once and not remeasured until the other 19 sections have been similarly measured. For example, perhaps make the 20 section runs in five days so that at least one day separates replication runs.

MRM CONTROL CHART
WORK SHEET

DISTRICT – MRM NO. 1 DATE FEB 1972

SECTION	SI REPLICATION					$\bar{X}$	R
	1	2	3	4	5		
1	3.6	3.5	3.4	3.5	3.5	3.50	0.2
2	2.7	2.7	2.7	2.7	2.7	2.70	0
3b	3.5	3.6	3.3	3.4	3.6	3.48	0.3
4	2.5	2.3	2.2	2.3	2.2	2.30	0.3
5	3.9	3.9	3.9	3.9	4.0	3.92	0.1
7	4.5	4.5	4.5	4.4	4.5	4.48	0.1
8	3.5	3.6	3.6	3.8	3.6	3.62	0.3
9	4.4	4.4	4.1	4.0	4.3	4.24	0.4
10	4.4	4.5	4.3	4.5	4.5	4.44	0.2
11	3.9	4.1	3.9	4.1	4.1	4.02	0.2
12	3.2	3.3	3.1	3.0	3.1	3.14	0.3
13	2.9	2.7	2.7	2.6	2.7	2.72	0.3
14	4.0	3.8	3.9	3.9	3.9	3.90	0.2
15	3.1	3.2	3.2	3.1	3.2	3.16	0.1
16	3.5	3.6	3.5	3.4	3.5	3.50	0.2
17	1.6	1.6	1.6	1.7	1.6	1.62	0.1
18	1.9	1.8	2.0	2.0	1.9	1.92	0.2
19	4.0	4.0	3.9	4.0	3.9	3.96	0.1
20	3.0	3.2	3.1	3.0	3.0	3.06	0.2
21	3.7	3.9	3.8	3.8	3.9	3.82	0.2

Upper Control Limit
For $R = 2.11 \times \bar{R}$
$= 0.42$

$R_{Total} = 4.0$

$\bar{R} = \frac{R_{Total}}{20}$
$= 0.20$

Control Limits for
Mean $= \pm 0.58\bar{R} = \pm 0.12$

Fig B. Typical MRM work sheet.

measurements) obtained and entered on the work sheet (Fig B). The following values are then computed for each section:

(1) The mean $\bar{X}$ of the five test runs is computed and entered on the work sheet and the mean control chart (Fig C).

(2) The range R of the five test runs for each section is computed and entered on the work sheet.

(3) The mean range $\bar{R}$ is computed and entered on the work sheet.

(4) The upper and lower control limits for the mean control chart are computed by multiplying the mean range $\bar{R}$ by ± 0.58. This value is entered on the work sheet and plotted as two straight lines on the mean control chart (Fig C).

(5) The upper range control limit is computed by multiplying the mean range $\bar{R}$ by 2.11 and entering this value on the work sheet. This value is also plotted on the range control chart (Fig D).

Control checks involve making a set of five repeat runs over any one of the 20 test sections and finding the mean SI ($\bar{X}$) and range R (see Fig E). The difference between the current mean and the one initially established for the control section, as listed in the left-hand portion of Fig C, is then compared with the upper and lower mean control range. If this difference is greater than the control range, an OC condition can be suspected. The range provides an additional control check and is compared to the upper range control limit of Fig D. A range value falling outside this limit will also indicate an OC condition. By plotting the mean differences and range values, a past history or record can be maintained to help identify true OC situations.

MRM Control Operations. As indicated above, MRM control is provided by comparing the mean and range values from periodic test runs against control limits. When these values fall outside these limits, then OC conditions can be suspected. Periodic control runs should be made once per month when the MRM is not in use and at least once during each week the MRM is being used. Whereas the best testing procedure would be to randomly select the particular test section for any given control check, the worst procedure would be to use the same section for each test. If the former procedure cannot be practiced, then attempts should be made to at least try never to repeat the same section twice in succession and to include as many, preferably four or more, other sections between tests which involve the same section. For example, if during the first week, Section 1 of Fig C was run, then at least four weeks should pass before this section is again used for control purposes. The basic idea in the control

MRM RANGE CONTROL CHART

District ——— – ——— MRM No. ——— / ——— Date Feb. 1972

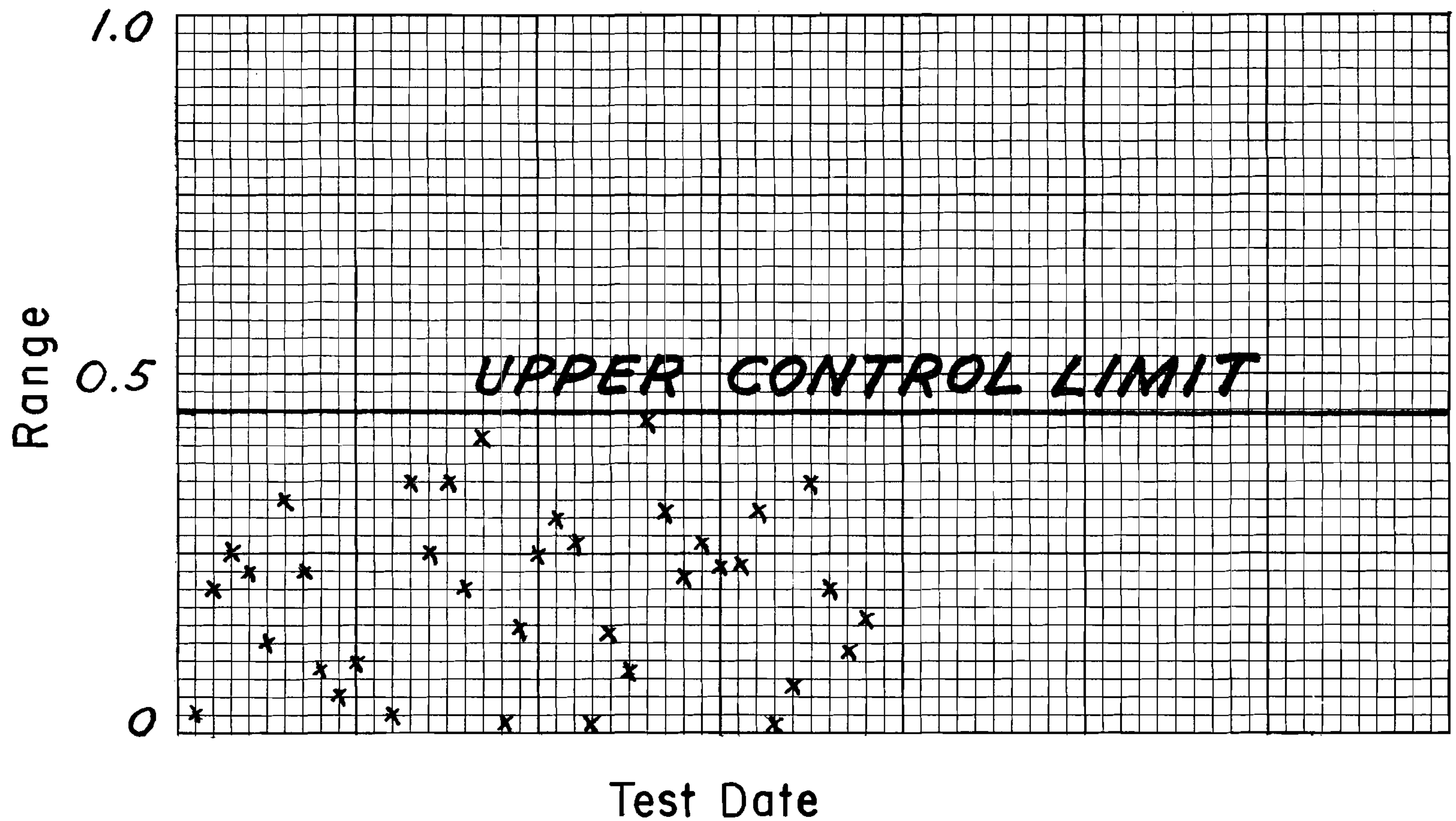


Fig D. Typical MRM control chart for range.

MRM MEAN CONTROL CHART

District ——— MRM No. 1 Date Feb. 1972

INITIAL MEAN

Section	$\overline{x}$
1	3.50
2	2.70
36	3.48
4	2.30
5	3.92
7	4.48
8	3.62
9	4.24
10	4.44
11	4.02
12	3.14
13	2.72
14	3.90
15	3.16
16	3.50
17	1.62
18	1.92
19	3.96
20	3.06
21	3.82

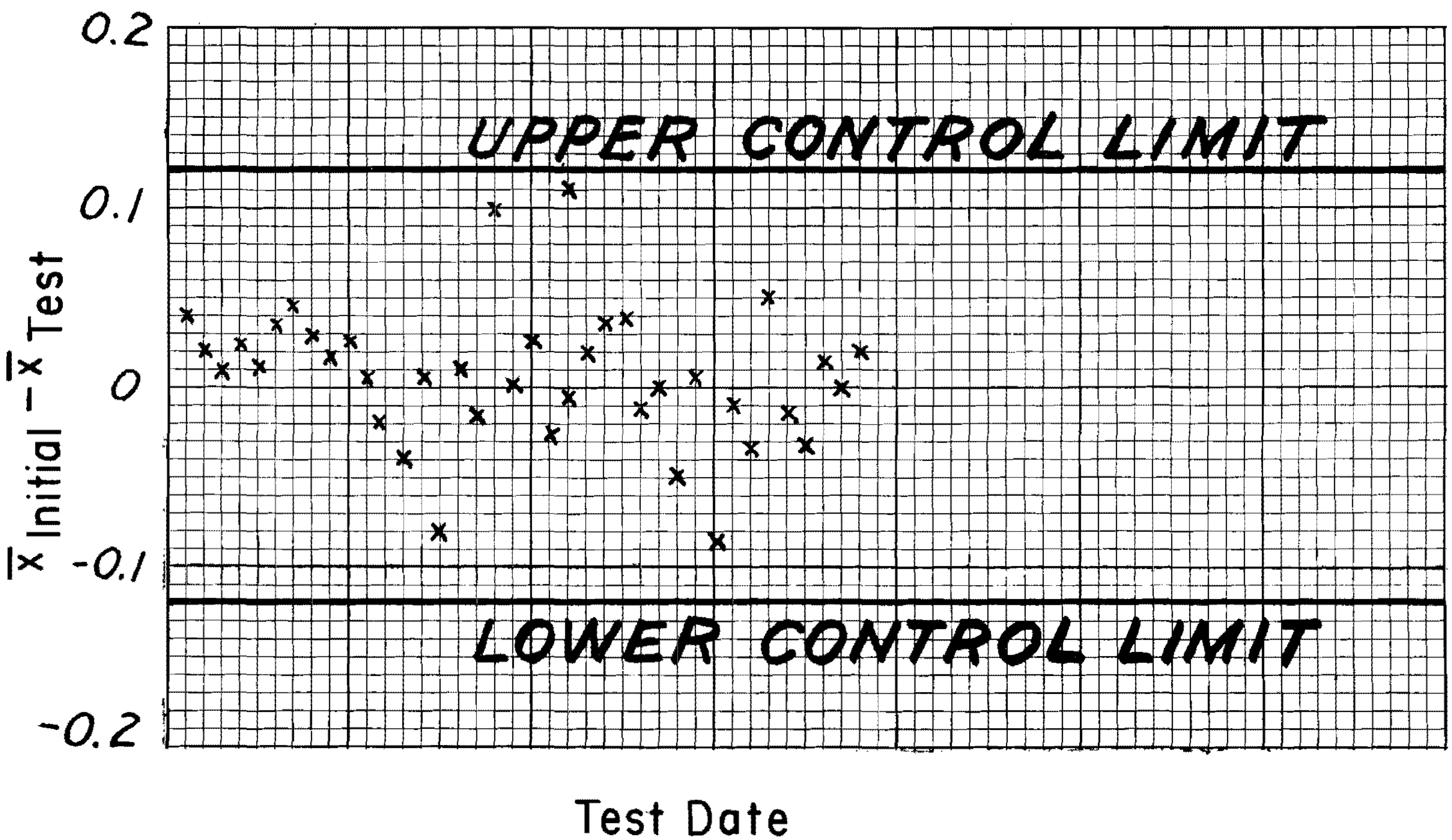


Fig C. Typical MRM control chart for mean.

WORK SHEET FOR
MRM CONTROL RUN

DISTRICT ____–____ MRM NO. ____/____

DATE ____FEB 1972____ SECTION ____–____

$\bar{X}_{INITIAL}$ (INITIAL SI AVERAGE) = ____3.2____

Run	SI
1	3.2
2	3.4
3	3.5
4	3.1
5	3.1

Sum SI = 16.3

$$\bar{X}_{CURRENT} = \frac{\text{Sum SI}}{5} = 3.26$$

$RANGE = SI_{MAX} - SI_{MIN}$ = 0.4 Enter on Range Control Chart

$\bar{X}_{INITIAL} - \bar{X}_{CURRENT}$ = -0.06 Enter on Mean Control Chart

Fig E. Typical work sheet for MRM control run.

procedure is to determine if the MRM is giving the same measurements, within its measurement errors. Since measurement errors can and will occur, the control limits are used to identify extreme occurrences of these measurement errors. These errors are based on the individual MRM and the control sections used; thus the importance of insuring proper selection of these sections and a proper testing procedure is evident. As indicated, an OC condition can be suspected when either the range or mean control limits are exceeded. If a control limit is exceeded on either the mean or range (or both), the first action, which should be immediately taken, is to carefully examine the MRM device and the vehicle in which it is installed for the possible problem source. If no problem source can be found, then a possible OC condition should be reported before further use of the instrument. If a suspected problem source can be found it should be corrected, and then the MRM control procedures should be performed on five of the control sections, i.e., 25 total runs. If all five tests indicate proper operation, then no further action is necessary. If, however, an OC condition again occurs on any section, it should be reported.

CONTROL FORMS

MRM CONTROL CHART
WORK SHEET

DISTRICT __________ MRM NO. __________ DATE __________

SECTION	SI REPLICATION					$\bar{X}$	R
	1	2	3	4	5		

Upper Control Limit
For $R = 2.11 \times \bar{R}$
= __________

R_{Total} = __________

$$R = \frac{\bar{R}_{Total}}{20}$$
= __________

Control Limits for
Mean $= \pm 0.58\bar{R}$ = __________

MRM MEAN CONTROL CHART

District ____________ MRM No. ________ Date ________

INITIAL MEAN

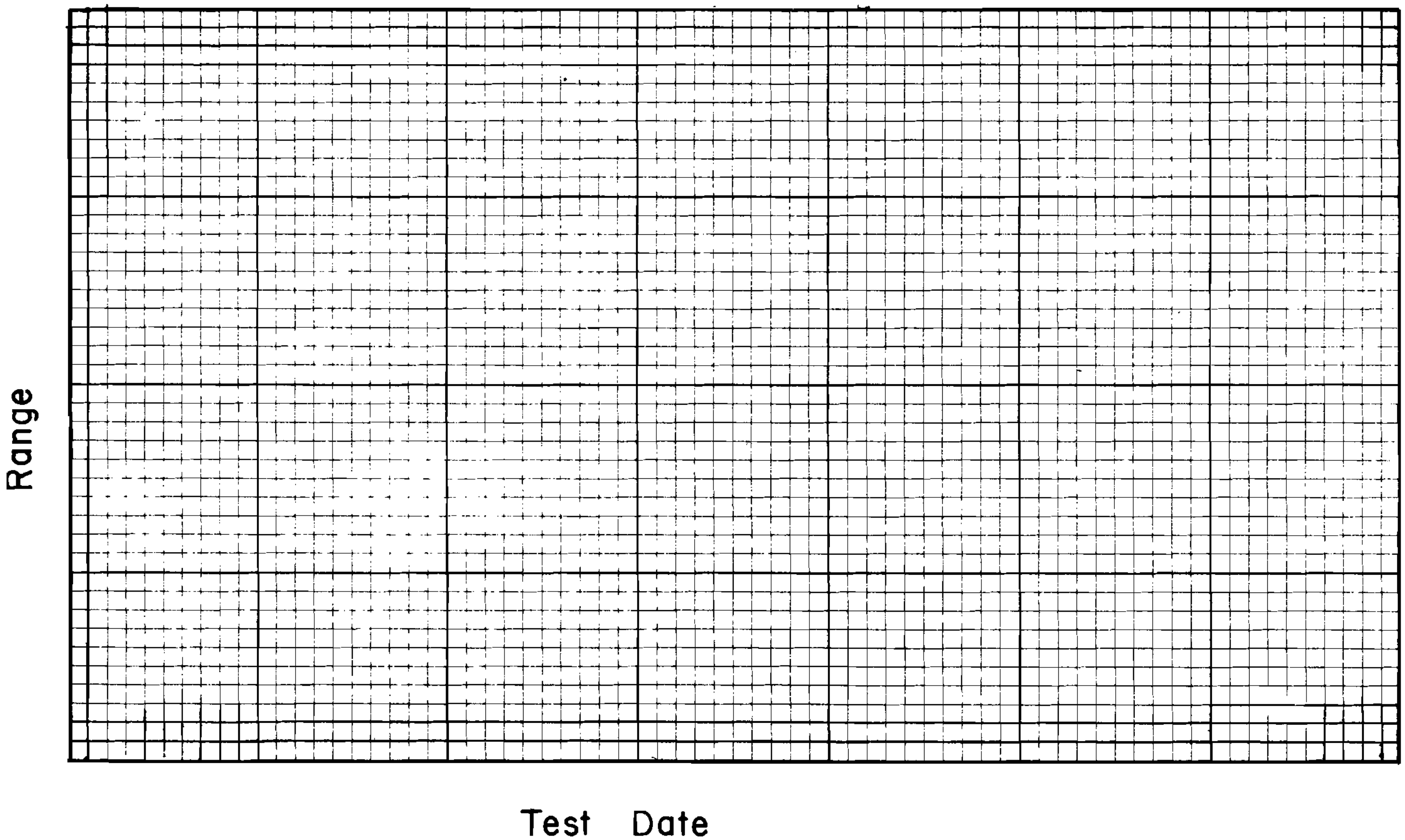
Section	$\bar{X}$

$\bar{X}_{Initial} - \bar{X}_{Test}$

Test Date

MRM RANGE CONTROL CHART

District ____________________ MRM No. __________ Date ___________



WORK SHEET FOR MRM CONTROL RUN

DISTRICT ____________ MRM NO. ____________

DATE ____________ SECTION ____________

$\bar{X}_{INITIAL}$ (INITIAL SI AVERAGE) = ____________

Run	SI
1	______
2	______
3	______
4	______
5	______

Sum SI = ______

$$\bar{X}_{CURRENT} = \frac{\text{Sum SI}}{5} = \_\_\_\_\_\_$$

$RANGE = SI_{MAX} - SI_{MIN} =$ ______ Enter on Range Control Chart

$\bar{X}_{INITIAL} - \bar{X}_{CURRENT} =$ ______ Enter on Mean Control Chart

APPENDIX 2

DESCRIPTION OF MAYS RIDE METER

The Following are

Excerpts From

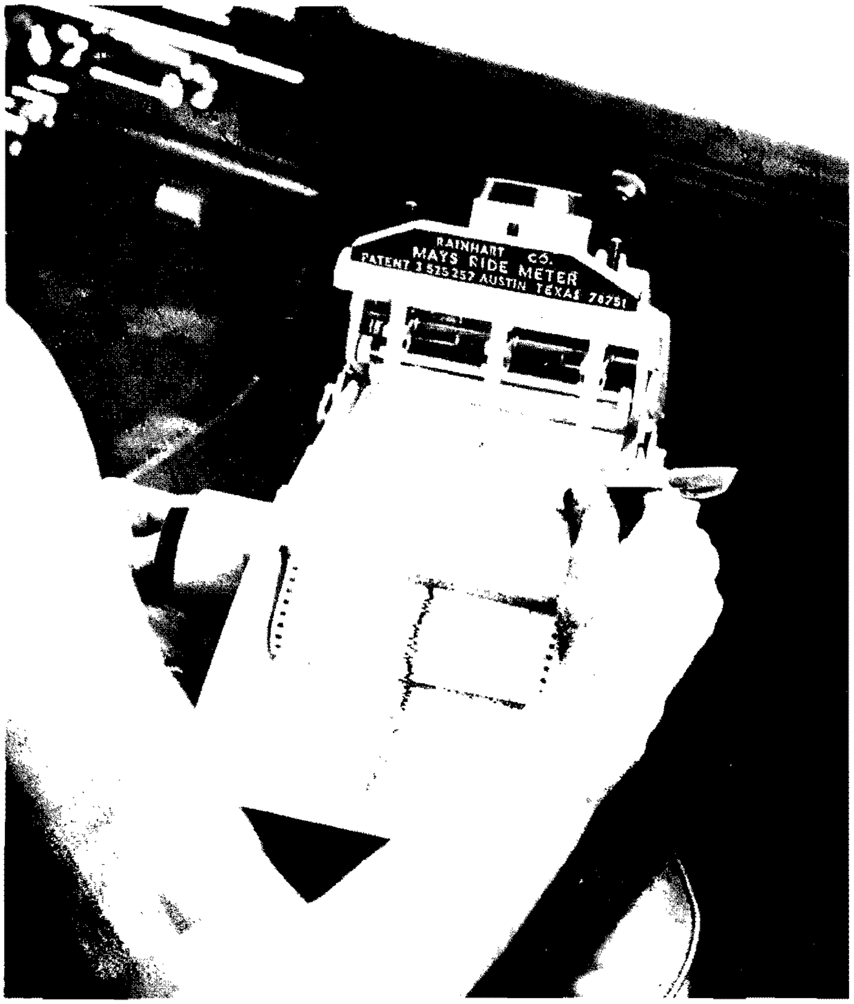
MAYS RIDE METER BOOKLET (Ref 9)

and are Pertinent to This Investigation

The incomparable

MAYS RIDE METER

for pavement surveillance



Purpose—The MAYS RIDE METER is used to most conveniently and economically evaluate or compare pavement surfaces; a practical, permanent and significant record is immediately available for easy interpretation in field or office.

Uses—

MAINTENANCE

- Help decide where best to spend available funds
- Evaluate before-and-after overlaying or surface treatment
- Early warning can signal preventive maintenance before pavement or base failure.
- Assist in dispatching repair crews

CONSTRUCTION

- Evaluate base coarse smoothness lift by lift
- Pavement acceptability.

INVENTORY MANAGEMENT

- Surveillance over months or years

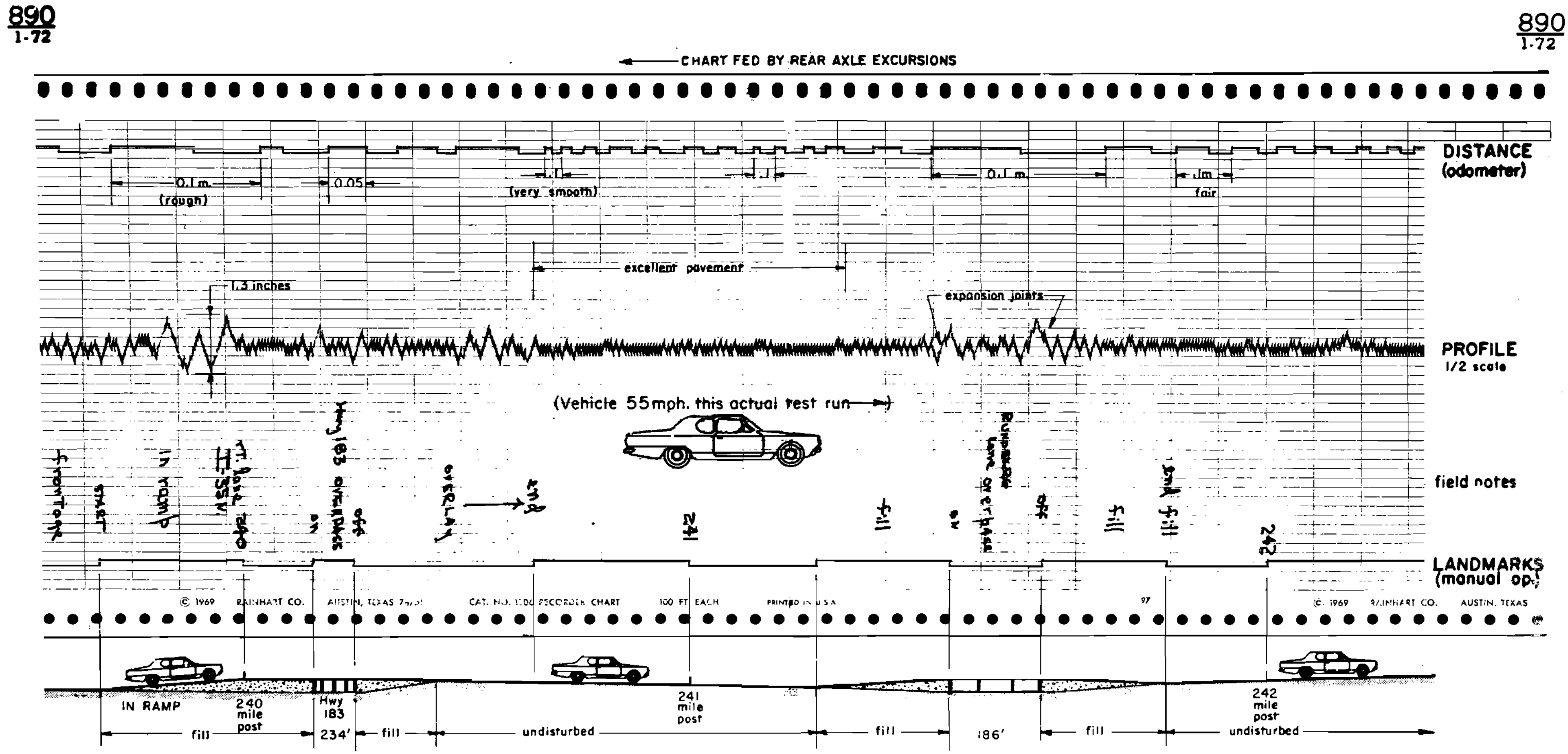
RESEARCH

The **MAYS METER** is an inexpensive instrument that continuously logs the pavement surface by recording magnitude, direction and summation of rear axle to body excursions of its parent automobile together with synchronized distance increments and landmarks. This portable instrument, tethered only by an electric cord, is placed in the operator's lap or on the front seat and is operated at traffic velocities.

The **record** is a six inch wide "Z" fold strip chart (see center spread) uniquely fed at a variable rate to sum roughness: Ivan K. Mays deserves full credit for this breakthrough. On this chart is superimposed three synchronized traces which display.

- SUMMATION of roughness over any desired distance;
- NATURE of the roughness,
- LOCATION of pavement defects,
- MILEAGE ticked off by 1/20th mile increments;
- LANDMARKS and
- FIELD NOTES simultaneously jotted on the chart with occurrence of the happening.

Patent No. 3525257



Resolution of the transmitter, attached to the body, is one electric impulse for each 0.1 inch of up or down axle displacement.

Variable rate chart feed is in increments of 1/64 inch for each and every 0.1 inch of rear axle/body excursion. Perfect pavement will not drive the chart! Rough pavement will produce plenty of paper. Hence, the length of paper produced when divided by the known distance traveled is a meaningful index of roughness.

A distance (top) trace automatically zigs for 0.05 miles and zags for 0.05 miles, recording information generated by an odometer. Since this is independent of the chart feed, the longer the zig or zag, the rougher the pavement. In other words, the length of each zig or zag is the sum of the roughness for its 0.05 mile and also brackets the location of any particular feature.

The landmarks (bottom) trace alternately zigs or zags at the touch of a push-button to pinpoint the beginning or ending of a test section, bridge or overlay; the location of street or highway intersections or surface imperfections can also be fixed.

Field notes are directly written on the flowing chart at the time of the happening; this avoids the bother, expense, delay and possible errors in transcribing. A convenient, illuminated desk is provided.

The **profile** (center) trace follows the rear axle excursions in the same direction and at half the magnitude thus displaying surface peculiarities.

Fidelity. The variables of the record are reduced to the individual habits of the vehicle. If the instrument's maximum rate of response is exceeded (climbing out of a deep pot hole too rapidly, for example), the center pen will fail to return to zero; returning to zero is positive proof of performance. These exceptions can then be rerun at a lower speed or managed analytically. Any point recorded on the chart can be located on the highway.

Consistency. In actual experience, standard size vehicles of different makes, models and loading vary in the magnitude of transmitter output but give quite similar signatures. A stable test strip composed of typical pavement types, can be used to correlate a fleet; a calibration derived from more sophisticated equipment operated on this test strip can provide a second generation standard.

Interpretation—

SUBJECTIVE: a glance will compare two pavements, their relative condition and trouble spots. Individual pavement discontinuities (R.R. tracks, occasional bridge ends, etc.) are dramatically displayed and can be put in their proper perspective.

ANALYTICALLY: The length of chart for any indicated mileage traveled is converted to unit values, corrected for individual vehicle performance and can be statistically reduced to vertical inches per mile or to a serviceability index. The mileage traveled can be derived from the distance trace; a known mileage between landmark ticks can also be used. Multiple or overlapping summations are practical.

Electronic circuits—

The top and bottom pens are solenoid activated:

- the distance pen is controlled by a special odometer containing a microswitch which is automatically cam actuated to alternately make for 0.05 miles and break for 0.05 miles; and
- the landmarks pen is controlled manually by a push-on push-off switch.

The transmitter, permanently installed in the trunk, has a 4 track mylar film program mounted in its direct drive, axle attached shuttle; this program is read by 4 tiny (1/16 in. dia.) photocells whose output is refined at the recorder by the first I. C. (integrated circuit chip) and controls a 4 track, two stage amplifier transistor-switch card; hence, the high response oscillating stepper motor drives the profile (center) pen employing a rack-and-pinion.

These refined impulses from the first I.C. are also fed into a second I.C. which unscrambles and a third I.C. (a flip-flop) which reprograms them to control a second 4 channel 2 stage transistor-switch card; thus the chart drive stepper motor rotates in a fixed direction one step for each and every transmitter generated impulse. The two identical 4 phase stepper motors are R/C excited. All components (photocells, solenoids, exciter lamp, stepper motors and chips) are 12V DC and are compatible with automobile 12 volt, negative ground electric systems.

CAT. NO. 890 MAYS RIDE METER—Complete with solid state recorder; photoelectric transmitter, modified odometer, required connections; three pens; 1006 Recorder Chart, Pkg. 300 ft; and Mays Ride Meter Booklet. Approx. Ship. Wt. 40 lb.

CAT. NO. 1006 RECORDER CHART, PKG/300 FT.—Three 100 ft. lengths for use with 890 Mays Ride Meter. Approx. Ship. Wt. 2 lb.

Specifications—The recorder provides a record of road surface roughness from the relative motion between body and rear axle housing of a full size, solid rear axle automobile. The recorder and associated systems employ electrically transmitted data utilizing current solid state design in all circuits. The transmitter detects both direction and magnitude of relative vertical motion between the automobile body and rear axle housing with 0.1 inch resolution. Its range and response allows operation of the instrumented vehicle over normal surfaced roads at speeds in excess of 50 miles per hour under normal safe driving conditions. The transmitter output commands the pavement profile (center) pen to duplicate rear axle excursions at half scale and to also advance the chart paper 1/64 inch for each 0.1 inch increment of excursion both up or down. The distance (top) trace automatically records 0.05 mile increments; this pen is controlled from a special odometer. The landmarks (bottom) trace (providing pinpointing of any associated event) is push-button controlled; a desk is provided (allowing convenience when writing field notes simultaneously with the happening) The 6 inch cast aluminum recorder employs sprocket driven (for positive drive) Z-fold chart pack (for quick and convenient access to the recorded data). Flip-up loading is provided (to eliminate chart threading). A desk light is furnished (for convenience in after-dark operation). The recorder employs easy access for service and maintenance of all electric and mechanical components. Plug-in printed circuit boards are used (to allow in-field replacement). Electric cabling allows freedom of recorder location and operation in any near horizontal position in the front seat of the automobile; when unplugged, the recorder can be removed from the vehicle. The entire system operates from a nominal (no modifications necessary) 12 V DC negative ground automobile power system

Additional information including vehicle recommendations, operating instructions, interpreting guide and installation are contained in your free copy of the Rainhart Cat. No. 890 MAYS RIDE METER BOOKLET.

History. Pavement roughness measuring devices using the car's body as a reference platform and a wheel or axle as a sensing device can be traced back to the early 30's—there is nothing new here. The hang-up has been inventing a practical format for the data. Mr. Mays' variable rate of chart feed allowing continuous summation of roughness, is the breakthrough. His is the most practical system of data presentation which has been advanced.

This is a second generation instrument replacing the original Mays Road Meter (described in several highway publications). The changes improve:

- o convenience (a lap or front seat instrument replacing the original rigid trunk location);
- o accuracy (solid drive digital transmitter replacing cord drive with spring take-up);
- o ease of interpretation of the record (three side-by-side pens mounted on a common track replace swing pens which were staggered along the record), and
- o distance is recorded by 1/20th mile increments instead of 1/10th.

The unique presentation of data has been carried forward!

Vehicle. The Mays Ride Meter faithfully records the ride of the rear of an automobile: this makes the vehicle the critical element in the apparatus (as well as the expensive portion of the package).

The car body is the reference platform for all measurements and hence the title: Ride Meter. To use an absurd but appropriate illustration: if the rear axle were unsprung (solid blocking, no springs or shock absorbers like an ox cart), the Ride Meter transmitter would generate no signal and the recorder would call all pavement perfect! (For ox carts, that is!) The Detroit "boulevard-ride" is highly desirable! But even this can be overdone.

Dimensions: A portable instrument; width 11 inches, length 18 inches, height 8 inches, weight 17 lb. Operates on 12V DC negative ground automobile systems.

An ideal vehicle would have:

- o a full size body
- o front engine
- o solid rear axle
- o coil springs (leaf springs tend to depart from Hook's Law because of internal friction of the scrubbing leafs)
- o drag links (to keep the axle from wandering fore and aft)
- o rear sway bar (to prevent the axle from wandering laterally)
- o firm shock absorbers (the suspension must be hard enough to not bottom out readily but soft enough to generate adequate transmitter action) **VERY IMPORTANT**
- o round tires (preferably ground since cyclic out-of-roundness will appear as surface roughness)
- o dynamically balanced tires (ditto)
- o a sufficiently accurate original equipment odometer and speedometer. (Tire circumference is the most frequent culprit. Automobile dealers can furnish a variety of transmission/speedometer take-off gears—one tooth difference is about 5%)
- o and air conditioning. (This is highly desirable in hot climates quite as much for the reliability of the electronic components as for the comfort of the crew. All solid state circuitry operates more reliably in a cool, dry environment; stepper motors and large resistors dissipate heat more readily).

Tire pressure, temperature (particularly of the shock absorbers), weight of load and amount of gas in the tank, also affect the ride.

The above is offered as a guideline for optimum instrument utilization. Actual experience in comparing the variations among well sprung and damped vehicles shows that the differences are primarily in amplitude; the signature is not significantly affected.

Driver factor. In addition to the unique mechanical characteristics of the vehicle, the record also reflects driver behavior. Only by traveling at a constant velocity guided smoothly along the wheelpaths can a true picture emerge. The rear of the car squats when accelerating and lifts when braking thus generating pitching; the vehicle rolls when blanketed by a passing truck or traveling in a cross wind, and yaws when changing lanes or traveling out of the wheelpaths. These extraneous conditions change the car's attitude and might be recorded as roughness.

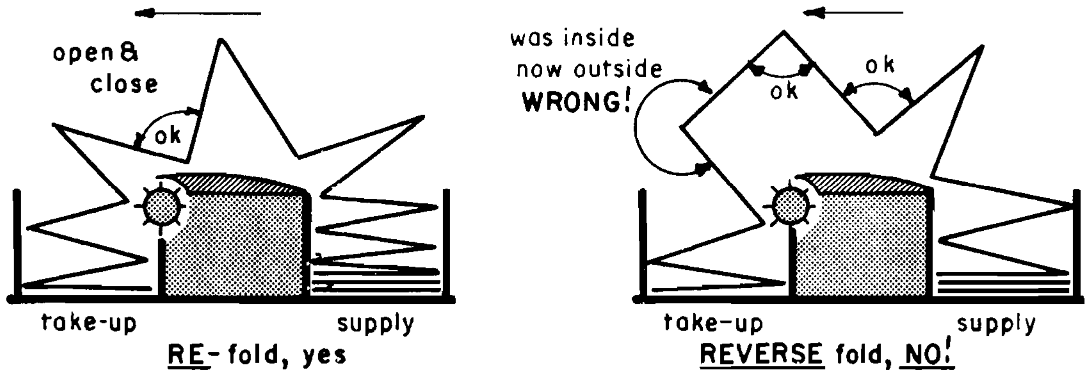
This test requires a conscientious chauffeur!

Crew. A two man team is recommended. Maintaining a constant speed in a precise wheelpath and solving the problems of safe driving requires the full attention of the driver. Navigating and recording landmarks and pertinent field notes on the flowing chart, requires the full attention of the observer. In practice (since the observer requires almost no training) a local Superintendent can best serve because he is well acquainted with his roads and their landmarks and problems; he will follow up on their maintenance.

OPERATING PROCEDURE

Chart (Rainhart Chart No. 1006). A 6 inch wide "Z" fold chart, perforated at each fold to allow easy tear-off, has ¼ inch pitch sprocket drive perforations which provide positive drive. The chart has been ruled 1/10 inches longitudinally for easy counting of local surface deviations. The chart has also been ruled laterally with lines spaced ½ inch apart to aid in comparison of accumulated roughness.

To **load the chart**, unwrap a fresh package. Unlatch both sides of the recorder and open the hood. Lift the desk. Unfold a few sheets and lay the supply in the hood end so oriented that the chart feeds its printed side up across the platen. (It does not matter on which side the round perforations or the slots fall). Refold a couple of sheets into the take-up box. **Caution:** the spring in the Z-fold will automatically refold—don't expect it to reverse fold! (The only refolding mechanism is the spring of the folds themselves!).



Never open a fresh package until it is needed because the chart can get soggy and lose the necessary spring hinge action.

Engage the drive perforations in the drive sprockets (make sure the chart is square and not skewed one perforation) and lower the desk. Lower the hood and latch it. With the MAYS RIDE METER turned OFF (pen lifter up) manually feed an inch or two (to smooth out the chart) by thumbing the teeth of the drive sprocket (on the right side housed in the landmarks switch box).

To install the pens: Use thin-line felt-tip markers. The three traces can be color coded.

With the pen lifter down, install so that the pen tips extend just enough to <u>elevate</u> the pen holders <u>slightly</u> off the pen lifter bar. Adjust the individual height of the three pens so that all toe the line; this is necessary to make the data of the three traces coincide in <u>straight lines across the chart</u>. Make sure that the pens are lifted off the chart when the pens are raised and the recorder is OFF (by rotating the pen lifter up).

Manually center the (middle) profile pen laterally.

OFF-ON switch is actuated by the pen lifter handle on the right hand side of the recorder (OFF, pens are up; ON, pens are down). <u>NO</u> warmup period is necessary.

Velocity. The performance of any vehicle is sensitive to velocity. On fair-to-good pavement, 50 mph. is recommended. If recording long undulations of otherwise smooth pavement, much higher velocities, perhaps up to 70 mph., will be required. On the other hand, when running city streets or poor pavement, much slower velocities (perhaps 25 mph.) is not unreasonable and 10 to 15 mph. may be quite fast enough in extreme roughness or railroad track crossings that are in bad need of repair.

The velocity must match the task in hand!

Avoid velocities associated with the vehicle's natural resonance points.

Test run. With the Mays meter loaded and checked out and the vehicle stabilized at the desired velocity and direction, lower the pens shortly before the road test is to begin. Coincidentally with starting the run, zero the odometer and press the landmarks button. Record landmarks, observations and pertinent data such as:

run number; date; time; location or highway number; direction of travel; lane traveled; length of test run; weather; etc.

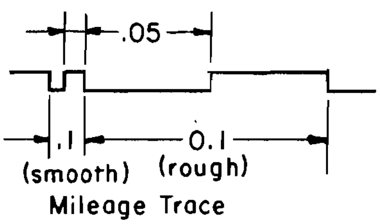
Make sure that enough data is gathered and recorded— these rapidly accumulating records are impossible to sort out from memory.

When finished, mark the end of the run, raise the pens and manually advance the paper until the pens are across the next (perforated) fold—a convenient tear-off. Decide if the record is usable—if not, modify the procedure and rerun.

Tracking rate. The response of the stepper motors is faster than 10 milliseconds (1/100 second); this will track roads in poor condition and railroad corssings at reasonable velocities. The recorder will either track with complete fidelity or will fail to return to its arbitrary zero telling the operator that axle excursion velocity exceeds the instrument's ability to read thus saying: "Rerun slower, please!" Turning the recorder **OFF** (by lifting the pens with the pen lifter lever) will unlock the stepper motors electrically and allow manual profile pen rezeroing or chart advance.

Comparing traces. There is no physical reason for not changing color code and superimposing a rerun on the same (refolded) chart. In practice, however, it is more practical to make runs on independent strips and compare them side by side thus allowing the strips to be moved longitudinally to establish the most convenient match for any area under scrutinization.

RECORD & INTERPRETATION



(1) **Distance** (top trace),is controlled by a special odometer, zigs for 0.05 and zags for 0.05 miles; one complete cycle = 0.10 miles. The distance the vehicle traveled is recorded independently of chart feed.

(2) **Profile** (center pen) records the axle/body excursions at ½ of the actual vertical distance traveled. The pen moves by steps of 1/20 inch at the command of each impulse from the transmitter (1/10 inch). This pen is rack-and-pinion driven by a stepper motor (located on the top of the instrument hood); the motor reverses with each change in axle direction. Inconsequential axle movement of less than 0.1 inches is filtered out at the transmitter and is not recorded.

The nature of the pavement roughness is indicated by the profile (center) trace. A pothole, dip or swell will be recorded as a wide undulation

spread over lots of chart length; short waves of consistant roughness will appear as uniform

narrow amplitude, and very long waves will appear when the car's velocity is high enough to respond.

(3) **Landmarks** are indicated near the bottom of the chart as zigs and zags responding to the operator's push button commands to pinpoint the location of the happening (event mark).

A convenient desk assists in keeping a play-by-play score card on the flowing chart eliminating the bother, expense or danger of errors in transcribing field notes. A pilot/desk lamp in the handle allows after-dark operation.

Roughness summation. The chart, driven by a second (but identical) stepper motor (located on the left side of the recorder), is moved 1/64 inch for each 1/10th inch or 1 inch for each 6.4 inches of total axle vertical travel (64 impulses). Each impulse (representing 0.1 inch axle movement) from the transmitter drives the profile pen up or down one step; it also drives the chart one step! This unique feature allows roughness to be summed continuously.

The Mays Ride Meter drives the chart 5 inches for every 32 inches of (total) vehicle axle vertical travel: the length of chart produced in a mile (indicated by the distance or landmarks trace) multiplied by 6.4 equals the total amount of axle excursions in inches per mile as referenced by the axle to body movement.

The less chart produced in a standard distance traveled, the smoother the pavement. And vice versa.

Since the amount of axle movement generated by the highway will vary with the vehicle and its condition, a multiplier must be determined if the unit quantity of chart is to be correlated with the vertical inches of pavement roughness as determined by other measuring systems. This suggests:

A standard local test course. A conveniently located mile of stable (and not too heavily traveled pavement) should be used as a local second generation standard. It would be ideal if several qualities of pavement were represented in this stretch. This lane can be occasionally calibrated with more sophisticated pavement evaluation equipment if it needs to be correlated; or a vehicle factor can be derived to take into account the car's individual habits.

THE AUTHORS

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