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16. Abstract

The use of profile statistics from designated road sections has proved to be an effective method of Maysmeter calibration. For best results, the statistic used must be tailored so that it quantifies what Maysmeters, as a class, actually measure regardless of the intended use of the measurements. For this purpose, a family of profile summary statistics based on the concept of Root-Mean-Square Vertical Acceleration (RMSVA) was developed. Some of these statistics have been found to correlate strongly with Maysmeter response. Moreover, the relationships are linear, much as the relationships between different Maysmeter units are linear. When selected RMSVA indices are combined to form a serviceability index representing "Maysmeter roughness," an effective calibration standard results. This RMSVA-based reference, termed SIV, exhibits distinct advantages over the profile statistic (SI2) used previously for calibration. First, because of its higher correlation with Maysmeter readings, SIV allows more accurate calibrations; that is, two Maysmeters calibrated at different times are more likely to agree when measuring the same road. Second, because of its relative simplicity, SIV is a more consistent and precise measurement of roughness when considered as a profilometer measurement. The repeatability of measurements, as shown by pairs of successive profilometer runs and also by consistency on sections that change very slowly, is much improved. Since it is less sensitive to the characteristics of profilometer hardware and is simple to compute, RMSVA is well suited for transition to the new digital profilometer which is being purchased by the Texas State Department of Highways and Public Transportation (SDHPT).

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road profile, statistics, Maysmeter, calibration, root-mean-square vertical acceleration (RMSVA), serviceability index, roughness

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THE USE OF ROAD PROFILE STATISTICS FOR MAYSMETER CALIBRATION

by

David W. McKenzie
W. Ronald Hudson
C. E. Lee

Research Report Number 251-1

Deployment of a Digital Road Profilometer

Research Project 3- 8-79-251

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

August 1982

PREFACE

This is the first report presenting results from Research Project 3- 8-79-251, entitled "Deployment of a Digital Road Profilometer." The study has two primary objectives: (1) to provide continuing support to the Texas State Department of Highways and Public Transportation (SDHPT) in all projects requiring profilometer data and (2) to assist SDHPT in the purchase and adaptation of a new digital profilometer system while insuring that Maysmeter calibration and other projects are not adversely affected by the transition to the new hardware.

The Surface Dynamics Profilometer (SDP) was originally developed under Research Studies 3-8-63-73, entitled "Development of a System for High-Speed Measurement of Pavement Roughness," and 3-8-71-156, entitled "Surface Dynamics Road Profilometer Applications."

A significant result of these studies was the development of a set of equations which can be used to predict a serviceability index that is based on road profile statistics. Present Serviceability Ratings (PSR) had been obtained from a 1968 subjective rating experiment on Texas roads; then the profile-based Serviceability Indices (SI) made it possible to interpret profilometer data in quantitative terms that relate more directly to ride quality or roughness. One of those indices, SI2, has served for a number of years as a relatively stable reference statistic for calibrating the SDHPT Maysmeters.

This report describes work by The University of Texas at Austin's Center for Transportation Research (CTR) to upgrade the existing Maysmeter calibration program by developing an improved profile statistic for use as a calibration standard. SI2 was not an optimal reference, primarily because of the presence of long wavelength roughness components that are not measurable by the Maysmeter. The new statistic, which results from a Maysmeter simulation that is based on Root-Mean-Square Vertical Acceleration (RMSVA), allows more accurate calibrations and will be more easily adapted to on-board computation with the new digital profilometer that was delivered in 1982.

The authors are pleased to acknowledge the work of Maitree Srinarawat, who assisted in much of the original data analyses through which the relevant RMSVA indices were derived. Also appreciated is the kind assistance of the State Department of Highways and Public Transportation representative, Brad Hubbard (D-10 Research), who furnished the Maysmeter data crucial to this study and who was first to point out certain deficiencies in the original calibration program.

Finally, special thanks are due to the CTR staff members who participated in this project, especially to Prentiss Riddle for his programming efforts and Elaine Hamilton, Barbara Allen, and Lyn Gabbert for their typing and proofing of the manuscript.

David W. McKenzie
W. Ronald Hudson
Clyde E. Lee

LIST OF REPORTS

Report No. 251-1, "The Use of Road Profile Statistics for Maysmeter Calibration," by David W. McKenzie, W. Ronald Hudson, and Clyde E. Lee, discusses the development of a set of summary statistics, termed Root-Mean-Square Vertical Acceleration (RMSVA) indices, useful for evaluating pavement roughness and predicting Maysmeter response. The SDHPT Maysmeter calibration program is revised to incorporate a linear calibration model based on an RMSVA-derived Maysmeter simulation.

ABSTRACT

The use of profile statistics from designated road sections has proved to be an effective method of Maysmeter calibration. For best results, the statistic used must be tailored so that it quantifies what Maysmeters, as a class, actually measure regardless of the intended use of the measurements.

For this purpose, a family of profile summary statistics based on the concept of Root-Mean-Square Vertical Acceleration (RMSVA) was developed. Some of these statistics have been found to correlate strongly with Maysmeter response. Moreover, the relationships are linear, much as the relationships between different Maysmeter units are linear. When selected RMSVA indices are combined to form a serviceability index representing "Maysmeter roughness," an effective calibration standard results. This RMSVA-based reference, termed SIV, exhibits distinct advantages over the profile statistic (SI2) used previously for calibration.

First, because of its higher correlation with Maysmeter readings, SIV allows more accurate calibrations; that is, two Maysmeters calibrated at different times are more likely to agree when measuring the same road. Second, because of its relative simplicity, SIV is a more consistent and precise measurement of roughness when considered as a profilometer measurement. The repeatability of measurements, as shown by pairs of successive profilometer runs and also by consistency on sections that change very slowly, is much improved. Since it is less sensitive to the

characteristics of profilometer hardware and is simple to compute, RMSVA is well suited for transition to the new digital profilometer which is being purchased by the Texas State Department of Highways and Public Transportation (SDHPT).

SUMMARY

One of the more important applications of the Surface Dynamics Profilometer (SDP) is to provide a stable calibration reference for response-type roughness measuring instruments. The latter devices, of which the Mays Ride Meter (Maysmeter) is typical, are relatively inexpensive and are used by many agencies for routine pavement monitoring. In Texas, a Maysmeter is calibrated by running the unit on approximately 30 designated flexible pavement road sections near Austin and then using statistical means to correlate its measurements with appropriate data obtained on those same sections with the profilometer.

The use of the profilometer as a reference vehicle has avoided the difficulty of trying to maintain a "stable" Maysmeter for this purpose; however, the problem of relating profile data to Maysmeter measurements must be solved if accurate calibrations are to result.

Two approaches are possible for developing profile statistics suitable for both roughness measuring device calibration and general roughness evaluation. The first is dynamic modelling of a hypothetical device with certain physical constants pre-defined and with sequences of profile evaluations taken as system input. For example, the Quarter Car Index (QI), which has been used successfully for Maysmeter calibration in Brazil, was so developed. Such indices are useful, however, not as simulations of particular instruments but simply as profile summary statistics whose

required high correlation with the target class of devices must be shown experimentally.

The alternative statistical approach which is described in this report is to obtain data from response-type roughness measuring instruments on representative road sections and then use regression techniques to select a profile statistic which the instruments are capable of measuring reliably.

In early 1978 a profile statistic which in principal relates to root-mean-square vertical acceleration (RMSVA) was investigated for use as a road roughness measure. It was able to describe quite well the behavior of eight Maysmeters (mounted on five trailers and three cars) all run on the Austin test sections in late 1977. A Maysmeter simulation statistic was thereby derived. The corresponding serviceability index, SIV, has since proved to be a definite improvement over the calibration standard, SI2, that was used previously. The latter statistic is based in part on certain power spectral estimates to which the Maysmeters are not sensitive.

For a period of two years, both SIV and SI2 were recorded during the quarterly profilometer runs of the test sections. Although the overall mean and variability of the sections were about the same for both indices, the SIV differences between repeated profilometer runs were only one-fourth to one-third as great as the SI2 differences. Furthermore, SIV is a more reliable measurement of roughness, as shown by consistency on sections having no major maintenance and experiencing little or no overall change in roughness during the period of study. The serviceability of 19 essentially unaltered sections declined an average of only 0.2 unit per year.

Although SIV was finally adopted as the calibration standard during January 1980, it was adopted in a provisional way that did not require modification of MRMCAL, the program that processes the calibration session data and produces a chart relating raw profilometer readings to serviceability estimates. The original version of MRMCAL employs a nonlinear regression algorithm. The recommended method is to use a revised program, MRMCAL2, to perform a simple linear fitting of the Maysmeter readings to an RMSVA-derived Maysmeter simulation.

Although the Maysmeter calibration problem motivated the development of RMSVA roughness indices, careful monitoring of the Austin test sections and other pavements has revealed surface properties that could never be detected by Maysmeters or by devices which reduce roughness evaluations to a single number. The RMSVA indices computed from a road profile can provide a "signature" that reflects roughness over a broad range of profile wavelengths. Distinctive signatures corresponding to certain pavement classes or types of deterioration have been tentatively identified and their interpretation remains as a promising subject for future research.

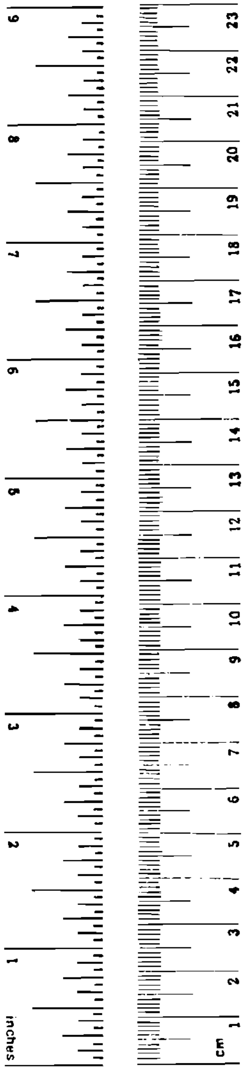
IMPLEMENTATION STATEMENT

It is recommended that the current SDHPT Maysmeter calibration program be fully revised to employ the linear calibration model described herein. A new version of the computer program which produces Maysmeter calibration tables is presented for replacement of the version now in use. The recommended change will simplify existing procedures and will result in more accurate calibrations.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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

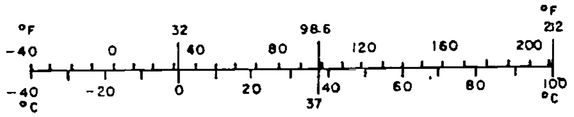


TABLE OF CONTENTS

CHAPTER 1. BACKGROUND AND APPLICATIONS OF THE SURFACE DYNAMICS PROFILOMETER

CHAPTER 2. ROOT-MEAN-SQUARE VERTICAL ACCELERATION AS A MEANS FOR EVALUATING ROAD ROUGHNESS

CHAPTER 3. DEVELOPMENT OF A MAYSMETER CALIBRATION STANDARD

CHAPTER 4. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

APPENDICES

CHAPTER 1. BACKGROUND AND APPLICATIONS OF THE SURFACE DYNAMICS PROFILOMETER

The Texas State Department of Highways and Public Transportation (SDHPT) has long had a vital interest in assuring the quality of its road system and in predicting pavement performance. To this end, the Surface Dynamics Profilometer (SDP) was introduced into the Department in early 1967. This system, which includes road profile measuring equipment along with data analysis programs that have been developed at The University of Texas Center for Transportation Research (CTR), continues to be an essential part of the state-wide program for planning, designing, operating, and maintaining the highway network.

As a roughness measuring device, the SDP is unique in that numerous roughness and performance statistics can be extracted from the profile data. The information can include ride quality or serviceability, evidence of various kinds of pavement distress, and even simulations of response-type roughness measuring devices. Accurate road profile measurements can be made at high speed, and because the measurements are essentially independent of vehicle suspension, they have shown to be very stable in time. For this reason, the SDP has functioned for the past eight years as the standard reference device for calibrating the SDHPT Maysmeters.

The original profilometer hardware, which is mounted in a 1966 General Motors passenger vehicle, records all profile data in analog form.

Consequently, a laboratory-based analog-to-digital process is required before profile summary statistics can be computed. This equipment, while still operational, is soon to be augmented and eventually replaced with a much improved digital system, which will provide usable roughness data while still in the field and will produce digital tapes for analysis with existing computer software.

SUMMARY OF PAST RESEARCH

The first SDP purchased by the SDHPT was manufactured by K. J. Law Engineering Company under patents of General Motors Corporation. The device was purchased in early 1967 after a thorough investigation of existing road roughness measuring equipment, as described in Research Report No. 73-1, "High-Speed Road Profile Equipment Evaluation." Subsequent to a shakedown phase in which various operating problems were found and eliminated, a road profile measuring system was developed which consisted of both the SDP and a companion A-D computer facility for converting analog profile data to digital form for computer analysis. The details of this system are described in Research Report No. 73-2, "A Profile Measuring, Recording, and Processing System." Research Report No. 73-4, "An Analog-to-Digital System," describes the Hewlett-Packard 2115 A-D system that has been operated by the Texas State Department of Highways and Public Transportation since 1969.

In order to obtain a meaningful roughness description from a measured road profile, efforts were made to correlate various summary statistics, such as slope variance, with Present Serviceability Rating (PSR). PSR is defined as the average subjective rating, on a scale from zero to five, of a road's ability to serve high-speed, high-volume, mixed traffic in its present condition. In the summer of 1968, two large-scale rating sessions were conducted by Center for Highway Research. Representative pavement sections were rated by a human panel after the profiles had been measured. A discussion of the rating methods and the first PSR prediction equations which resulted is provided in Research Report No. 73-3, "Pavement Serviceability Equations Using the Surface Dynamics Profilometer."

Under Research Study 3-8-71-156, improved analytical methods for obtaining more realistic and useful descriptions of the road profile were developed and much of the computer software which is currently in use was written. Improved PSR prediction equations were obtained, and significant progress was made toward identifying the profile characteristics which relate most directly to different types of roughness. In addition, use of the profilometer was extended to a wider variety of research and implementation areas.

In the early 1970's, the Department established a set of priority needs for roughness measurements, including the following:

(1) assessment of pavement performance for maintenance purposes,

(2) evaluation of the roughness of special pavement sections such as bridges and railroad crossings, and

(3) evaluation and priority determinations of pavement rehabilitation methods, both rigid and flexible.

To help accomplish these goals, the SDHPT acquired a group of Maysmeters to function as roughness measuring devices in various locations around the

State. Maysmeters respond to road roughness in a way that is dependent on vehicle suspension and other factors that may vary over time and between devices. Research Report 156-1, "A Correlation Study of the Mays Road Meter with the Surface Dynamics Profilometer" (February 1973), documents the development of a statistical model for predicting serviceability in terms of the Maysmeter roughness measure (inches of axle displacement per mile) for a given vehicle. More important, the profilometer-derived Serviceability Index (SI) was proposed as a reasonably stable standard against which different Maysmeters could be compared. Although the calibration standard SI was eventually replaced, the basic calibration procedures introduced at that time are still in use at SDHPT.

In Research Report 156-2, "The Use of Spectral Estimates for Pavement Characterization" (August 1973), a method for predicting the serviceability in terms of root-mean-square profile wavelength amplitudes is presented. The multiple regression model (SI2) contains 22 terms involving power spectral estimates extracted from the road profile. The model was considered successful in that 89 percent of the road-to-road variation in rating panel serviceability data was explained in terms of roughness amplitudes in the wavelength range of 8 to 87 feet. The success of the SI2 regression model encouraged a deeper investigation into the relationship between roughness and serviceability. In particular, this statistic alone was still not adequate for answering such pertinent questions as the following:

(1) What is the within-section roughness variation? For example, a given RMS roughness amplitude could be due to either a single large bump or many waves of smaller amplitude, etc.

(2) What is the effect of vehicle roll (due to right-left wheelpath deviation difference) on ride quality?

(3) What relationships can be established between specific kinds of roughness and known types of pavement distress?

(4) What features of the road roughness do users find most objectionable? What are their individual correlations with serviceability?

The research that followed helped to resolve some of these questions. This work is described in Research Reports 156-3, "Analysis of Characteristic Roughness Patterns in Pavements and the Relationship Between Roughness and Pavement Distress;" 156-4, "The Characterizations of Road Roughness on Bridge Decks and the Adjoining Pavement," and finally, 156-5F, "A Study of the Relationship Between Various Classes of Road Surface Roughness and Human Ratings of Riding Quality."

The computer program ROKYRD, which analyzes and plots filtered profiles, was an important product of the research effort. Digital filtering techniques allow specific profile wavelengths to be isolated and compared. Furthermore, frequency distributions in the form of percentile roughness amplitudes for each desired waveband are provided, as are the individual and combined serviceability estimates.

In early 1978, CTR again proceeded to investigate various profile summary statistics, this time in an effort to devise a better Maysmeter calibration standard. One statistic in particular, Root-Mean-Square Vertical Acceleration (RMSVA), was able to describe especially well the behavior of the Department's Maysmeters on the calibration test sections. The new calibration standard resulting from this work has since proved to be a definite improvement over the serviceability index SI2, which is partially based on power spectral quantities to which the Maysmeter is not sensitive.

The development of the RMSVA roughness statistics and their correlation with Maysmeters are described in this report, the first produced under Research Study 3- 8-79-251, "Deployment of a Digital Road Profilometer."

TYPICAL APPLICATIONS OF THE PROFILOMETER

A brief summary of current or recent SDHPT activities which are typical of possible future projects involving the SD Profilometer is given below:

(1) <u>Maysmeter Calibration</u> - Since early 1973, the SD Profilometer has provided, on a regular quarterly basis, the serviceability estimates for approximately 30 calibration test sections. A particular Maysmeter is calibrated by running it on the test sections, then scaling its measurements to fit the most current profilometer data. (In this report, the development of an improved calibration standard based on profile statistics is described.)

(2) <u>Evaluation of Construction Methods</u> - By comparing bridge surfaces constructed with longitudinal and transverse screening (Study 3-213), it was demonstrated that the latter process introduced more short-wave roughness. In a separate but similar study, the effect on roughness amplitudes of ski and tight-string procedures in hot mix laying was investigated.

(3) <u>Roughness at the Bridge-Pavement Interface</u> - Both the magnitude and the frequency of occurrence of this problem have been examined by

the profilometer. The goal is to establish a probable cause of this roughness and to make recommendations for design and maintenance.

(4) Dynamic Loading of Bridges - A computer program DYMOL uses profilometer data to predict the dynamic loading caused by a vehicle. This information has been used to suggest suitable speed limits on bridges which have experienced sagging.

(5) Evaluation of Overlay Methods - To study the performance of asphaltic overlays on CRCP, profiles of test sections in selected counties are being monitored on a yearly basis (Project 249).

(6) Evaluation of Rehabilitation Methods - The effect of pressure grouting on CRC pavements known to contain voids was investigated by examining profiles of test and control sections. The statistical summaries provided by ROKYRD indicated that roughness in the 25 to 50-foot wavelength range increased where grouting occurred. This supported other evidence that the slab was occasionally raised by the process.

(7) Implementation of Rehabilitation Methods - The profilometer strip chart has been used to estimate the quantity of material needed for an efficient level-up. Software available for the new digital profilometer will simplify this procedure.

(8) Pavement Materials - Profilometer measurements have been analyzed to determine the effect of sulfur-asphaltic mixtures on pavement quality.

(9) Pavement Distress Mechanisms - On a semiannual basis profilometer runs were made in connection with Project 224, "Detrimental Volume Changes in Expansive Clays in Highway Subgrades."

ADVANCED FEATURES OF THE DIGITAL PROFILOMETER

In addition to providing continuing support of SDHPT projects requiring road profile data, a major objective of Research Study 3- 8-79-251 has been the purchase and adaptation of a new digital profilometer to replace the existing hardware, which has been in use for more than 10 years. The principal operational advantages of the digital model are given below.

(1) Almost limitless range is provided for digital integration of electrical signals. Operating the old profilometer on grades sometimes overloads the integrators, thereby creating an artificial step in the profile.

(2) Variable digital filtering is incorporated in the new equipment. The profile cutoff frequency set by the operator remains fixed as the filtering system adjusts automatically to the speed of the vehicle.

(3) Calculation of various roughness statistics (e.g., Quarter-Car Index, RMSVA, etc.) is accomplished on board the vehicle. The main processor can be re-programmed, and new programs can be added.

(4) An electric typewriter input-output console for printing these statistics and for recording other run information will be

provided. Also, strip chart output will be available via a digital-to-analog conversion system.

(5) A larger and more functional van houses the equipment.

(6) A distance measuring system using the left front wheel of the profilometer vehicle provides a more accurate speed and distance input to the digital recording system.

(7) Self-calibration and self-checking of system operation are provided by programs in the on-board computer.

(8) A magnetic tape format which represents each profile data point by a 24-bit binary number is utilized. This allows for a resolution of .001 inch and a range of ± 8388.608 inches.

The new system, with its improved hardware and more compact configuration, is expected to be of greater benefit to the field engineer. Thus, in addition to serving as a standard calibration device for other roughness measuring instruments, the profilometer will be used even more extensively as a direct aid for pavement design and evaluation.

CHAPTER 2. ROOT-MEAN-SQUARE VERTICAL ACCELERATION AS A MEANS FOR EVALUATING ROAD ROUGHNESS

THE MAYSMETER CALIBRATION PROBLEM

Since early 1973, the Texas State Department of Highways and Public Transportation has calibrated its Maysmeters by running each unit periodically on approximately 30 pavement test sections near Austin. Each calibration session determines a relationship between a particular unit's measurements and the serviceability estimates of a Surface Dynamics Profilometer. The use of the profilometer as a reference vehicle has avoided the difficulty in trying to maintain for that purpose a typical Maysmeter whose response characteristics, it is hoped, never change. Instead, one is faced with the initial problem of relating Maysmeters to the profilometer. For example, one would expect that two Maysmeter trailers, being similarly constructed, would respond to more or less the same kinds of pavement properties. There is a good chance that their separate measurements are related by a simple, perhaps linear, function. The profilometer, on the other hand, measures only the road profile but does so with considerable accuracy and consistency. The problem is that the function relating the profile to a Maysmeter's measurements may not be simple and there is a possibility of choosing an inferior, possibly invalid, profile summary statistic as the calibration standard.

For a number of years, the approach in Texas was to calibrate each Maysmeter independently by fitting its measurements on the test sections to the equation

$$ln\ M \cong \beta \left[ln\ \left(\frac{5}{SI} \right) \right]^{1/\alpha} \qquad (2.1)$$

where

M = is the Maysmeter measurement (inches per mile),
SI = is the current serviceability index for the section, and
β and α = are nonlinear regression coefficients.

SI is itself a prediction equation developed independently to explain the results of a 1968 subjective panel rating of 86 sections in the Dallas-Fort Worth area (Ref 1). It contains 22 terms involving power spectral estimates computed from the digitized road profile.

The form of Eq 2.1 was obtained empirically after considerable experimentation (Ref 2), and served to provide each calibrated unit with an equation,

$$\widehat{SI} = 5e^{-\left(\frac{ln\ M}{\beta} \right)^{\alpha}} \qquad (2.2)$$

to convert its readings to serviceability indices which range from 0 to 5. Ideally, the adjustment of parameters α and β through calibration would account for physical differences between units or for changes in a given vehicle's suspension, tires, etc., due to wear or replacement of parts.

Eventually, a weakness in the Texas method became apparent when it was noticed that several of the test sections were persistent regression outliers; that is, they deviated significantly from the calibration regression curves and did so with each Maysmeter that was calibrated. Also, the effect of the calibration process was somewhat unpredictable. In the period preceding a calibration session a Maysmeter would provide $\widehat{SI}$ values of, say, 2.6, 2.7, 2.6, etc., for a succession of runs on a particular road. Afterwards, the same unit would return with new calibration parameters and provide, for the same road, $\widehat{SI}$ values of 3.2, 3.3, 3.2, etc., when it was doubtful that either the road or Maysmeter had physically changed. More likely, the group of rougher calibration test sections, for which there had been consistently poor agreement between the profilometer and Maysmeters, had changed since the previous calibration of that unit. Initially, there was an inclination to discard some of these sections due to their disproportionate effect on the calibration parameters; however, it was discovered that plots of $\widehat{SI}$ versus SI for different Maysmeters were almost identical with respect to the pattern of outliers. It then became clear that the calibration standard SI, not the choice of sections, was at fault as the statistic was obviously insensitive to roughness components measured with good repeatability by the Maysmeters.

Figure 1.1 is presented as a conceptual illustration of the advantage of calibrating four Maysmeters, for example, against a profile statistic which is specifically tailored to represent "MRM roughness." The responses of calibrated and uncalibrated devices are shown for four road sections with similar MRM roughness but with different present serviceability ratings (PSR). If PSR had instead been chosen as the calibration standard and the four units were "calibrated" at one time on sections 1 and 2 and at another

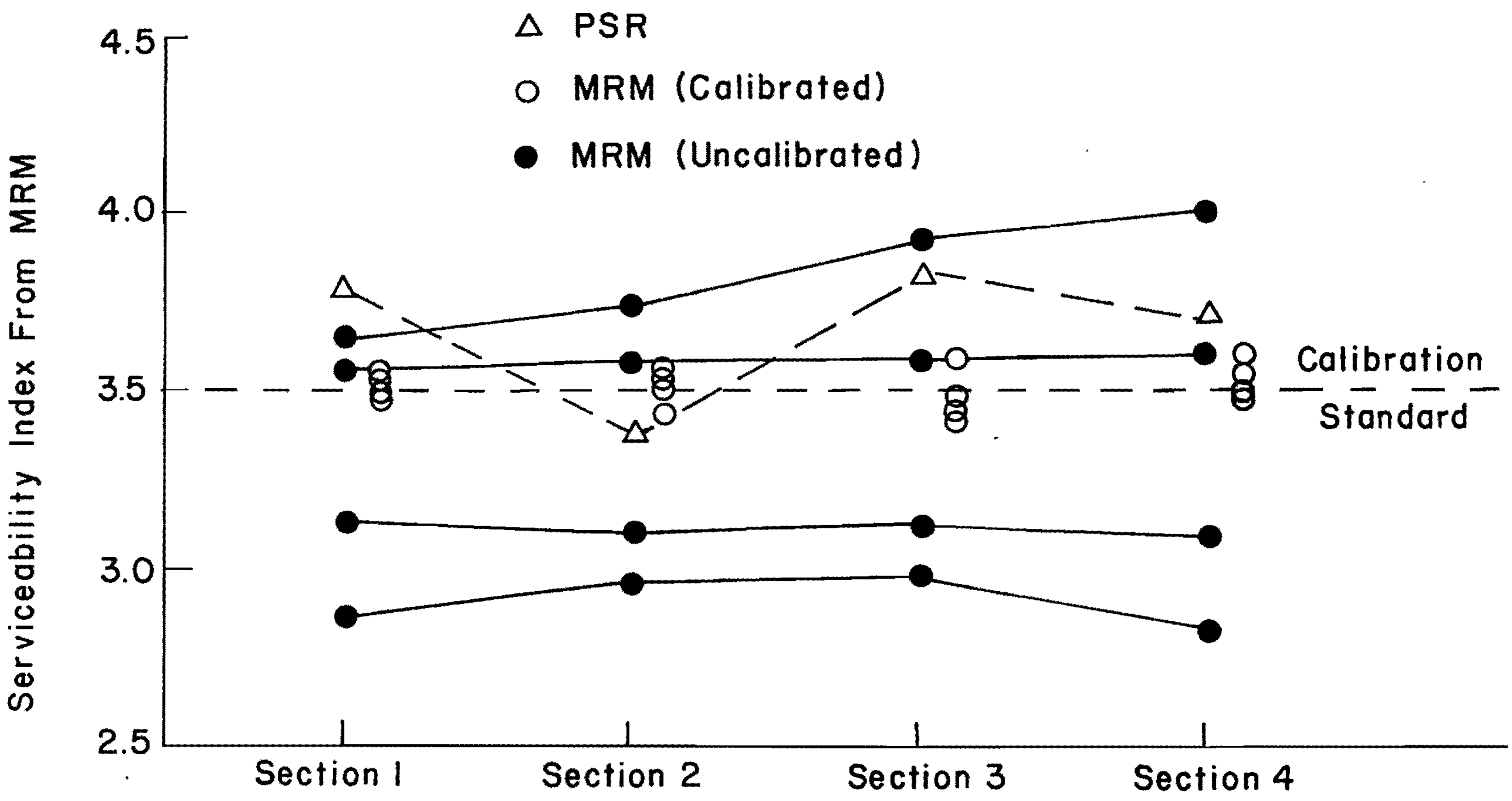


Fig 2.1. Example behavior of four Maysmeters on road sections with similar (MRM) roughness but with different present serviceability ratings (TSR).

time on sections 3 and 4, then it is clear that the units would acquire, in each calibration, a different formula for adjusting their raw readings, even if no physical changes in the devices have occurred. (Of course, an appropriate collection of road sections would have different levels of MRM roughness.) Although the procedure might succeed in bringing different units that happen to be calibrated at the same time into agreement, any variables in the assumed standard which are not measurable by the Maysmeter can only weaken the correlation between the devices and their common reference, thereby reducing the effectiveness of the calibration process.

On the other hand, if the formula resulting from the calibration were basically just a rescaling of measurements to insure the compatibility and time stability of different Maysmeters, then the essential information would not be degraded; it would always be available for deriving better relationships, for example, between MRM roughness and PSR or vehicle operating costs. While these latter correlations may be of utmost importance, they should not be confused with the prerequisite process of calibration.

The primary advantage of using a calibration reference specific for the particular kind of target device is that it results in more accurate calibrations. This means that it will be safer to assume that road A is actually rougher than road B even though the measurements indicating this were obtained at different times or with different "calibrated units." This is simply a benefit of the higher correlation between the instrument and an established reference. Pavement engineers would appreciate the ability to make valid comparisons of different pavements, which may vary only slightly with respect to apparent PSR but which can, nonetheless, reveal the effects of different maintenance practices or show significant trends over a period of time. Many response-type measuring devices, including Maysmeters, can measure with good repeatability certain traits of a pavement surface, or profile, which would not be as reliably observed by a rating panel.

The limitations of the original SI equation are not surprising for it was not developed in view of the Maysmeter's capabilities. Instead, power spectral and cross-spectral estimates from 64 frequency bands were considered in the regression model, the goal being to find a best predictor of Present Serviceability Rating (PSR) utilizing a profilometer's measurements. The SI equation has terms for roughness amplitudes for wavelengths up to 83 feet whereas it is known that Maysmeters run at 50 mph respond to a much smaller wavelength range--say 4 to 40 feet.

Consequently, an effort was made to improve the calibration procedure by selecting an alternative profile statistic for use as a standard. Our approach, which is described in the remainder of this report, was largely empirical in that we were not especially concerned with identifying or modelling the causal chain leading from the physical road profile to the roughness readings of a particular device. The need was to isolate a feature of the profile, something conceptually simple and easily computed if possible, which tends to quantify what Maysmeters as a class do, in fact, measure.

RMSVA - INTRODUCTION AND DEFINITIONS

Improving the Texas MRM calibration method required our searching for a profile summary statistic that simulated the response of a typical Maysmeter. Previous attempts to derive a predictor of Present Serviceability Rating

(PSR), which is a subjective assessment of roughness by users, deal principally with two basic methods for deriving roughness-related quantities from a sequence of wheelpath elevations. The first is computation of the power spectrum to obtain a set of indices that depend on the frequency of irregularities in the profile. The development of the previously mentioned SI equation, in which stepwise regression is used to select terms based on spectral estimates, is described in Ref 2. The second approach is that of digital filtering in which the disturbances in a set of contiguous pass-bands are isolated and examined for their effects on PSR (Ref 4). In this case, moving root-mean-square amplitudes are computed for each band, along with 50, 75, 90, 95, and 99 percentile values, which help distinguish between roads that have roughness either spread out or highly localized.

In our search for a statistic representing Maysmeter roughness, it was found that these techniques for detailed characterization of the profile were computationally wasteful and also rather sensitive to the profilometer speed and hardware configuration at the time of measurement. Instead, a very simple statistic, which is not so critically dependent on profile measuring technique and resolution, met the basic requirements of a calibration standard: (1) that it accurately represent, or simulate, the class of devices to be calibrated and (2) that an independent, time-stable method of measuring it be available. The component profile measure can be simply described as the *root-mean-square difference between adjacent profile slopes*, where each slope is the ratio of elevation change to distance over a fixed distance increment. Since the required computation is equivalent to estimating the second derivative of height with respect to time for an object in contact with the profile moving horizontally at a fixed speed, this quantity has been termed Root-Mean-Square Vertical Acceleration (RMSVA). It is defined more exactly as follows.

Let Y_1 , Y_2 , . . ., Y_N represent elevations of equally spaced points along one wheelpath of the profile. If s is the horizontal distance between adjacent points (sampling interval), then a simple estimate of the second derivative of Y at point i with respect to distance is

$$(S_b)_i = \frac{(Y_{i+k} - Y_i)/ks - (Y_i - Y_{i-k})/ks}{ks}$$

$$= (Y_{i+k} - 2Y_i + Y_{i-k})/(ks)^2 , \qquad (2.3)$$

where b = ks is the horizontal distance we shall call the <u>base length</u> corresponding to VA_b , the resulting measure of <u>Root Mean Square Vertical Acceleration</u> (RMSVA):

$$VA_b = C \left[\sum_{i=k+1}^{N-k} (S_b)_i^2 / (N - 2k) \right]^{1/2} \qquad (2.4)$$

where

N is the number of profile data points and C is a constant required for unit conversion. In this study, C = 5378 ft^2 / sec^2 is used to transform units ft / sec^2 assuming profile dimensions are in feet and the hypothetical object is travelling 50 mph.

Specifying the base length b is essential if RMSVA is to be a meaningful description of a road profile. Both theoretically and in practice, one finds that VA_b will tend to increase as b is decreased. Furthermore, in a typical profile, $\hat{V}A_b$ is most sensitive to half wavelengths approximating b . Wavelengths much larger than twice the base length contribute very little to RMSVA and, as a result, their effect on roughness is not revealed. On the other hand, roundoff errors in the computations, or measurements, will ultimately limit the resolution achieved by reducing the base length. In fact, it is this sensitivity of RMSVA to base length that renders it a useful statistic for describing a profile. RMSVA, therefore, should not be regarded as a single roughness index but rather as a set of indices, say VA_i , $i = b_1, b_2$, . . . , which collectively can reveal many of the pavement characteristics usually associated with roughness.

A Comparison of RMSVA With Slope Variance

Before discussing the relationship between MRM and RMSVA, we will first present an argument to the effect that RMSVA can be naturally identified with roughness--more so than the better known statistic, slope variance (SV). First, consider the response of RMSVA to a smooth sine wave of amplitude A and period $T = 2\pi/W$:

$$VA_b^2 = \frac{1}{T}\int_0^T \left[A/b^2\left(\sin W(t+b) - 2\sin Wt + \sin W(t-b)\right)\right]^2 dt$$

$$= \frac{2A^2}{b^4}(1 - \cos Wb)^2 ;$$

$$VA_b = \frac{A\sqrt{2}}{b^2}(1 - \cos Wb) \qquad (2.5)$$

$$= \frac{2A\sqrt{2}}{b^2} \sin^2 \frac{\pi b}{T}$$

$$= 2\sqrt{2}\, \pi^2\, A/T^2 \left[1 - \frac{1}{3} \left(\frac{\pi b}{T} \right)^2 + \frac{2}{45} \left(\frac{\pi b}{T} \right)^4 \quad . . . \right] .$$

Equation 2.5 reveals that when base length b is small in comparison to period (or wavelength), VA_b is proportional to A/T^2 . (This limit can also be obtained by differentiating the sine function twice, squaring, and integrating.)

For slope variance (SV) calculated at base length b , we instead have

$$SV_b = \frac{1}{T} \int_0^T \left[\frac{A}{b} \left(\sin W(t+b) - \sin Wt\right) \right]^2 dt$$

$$= (A/b)^2 \left(1 - \cos Wb \right) \qquad (2.6)$$

$$= 2\pi^2 \, (A/T)^2 \left[1 - \frac{1}{3} \left(\frac{\pi b}{T} \right)^2 + \quad . . . \right] .$$

Therefore, if SV were the accepted roughness measure, the "roughness" of a sine wave would depend only on its shape (A/T). This insensitivity of SV (for small b) to the scale of disturbance being measured is somewhat contrary to the usual notion of roughness.

An examination of road profiles which had been digitally filtered revealed, as one might expect, that the amplitudes of predominant variations in profiles are approximately proportional to their wavelengths (Fig 2.2). Figure 2.3 illustrates the response of VA_b to wavelength, assuming proportionality of amplitude ($A = T/2\sqrt{2}$), for several baselengths. The corresponding curves for SV would be horizontally displaced, depending on b , but would each approach a maximum of $SV = \pi^2/4$ as T increases.

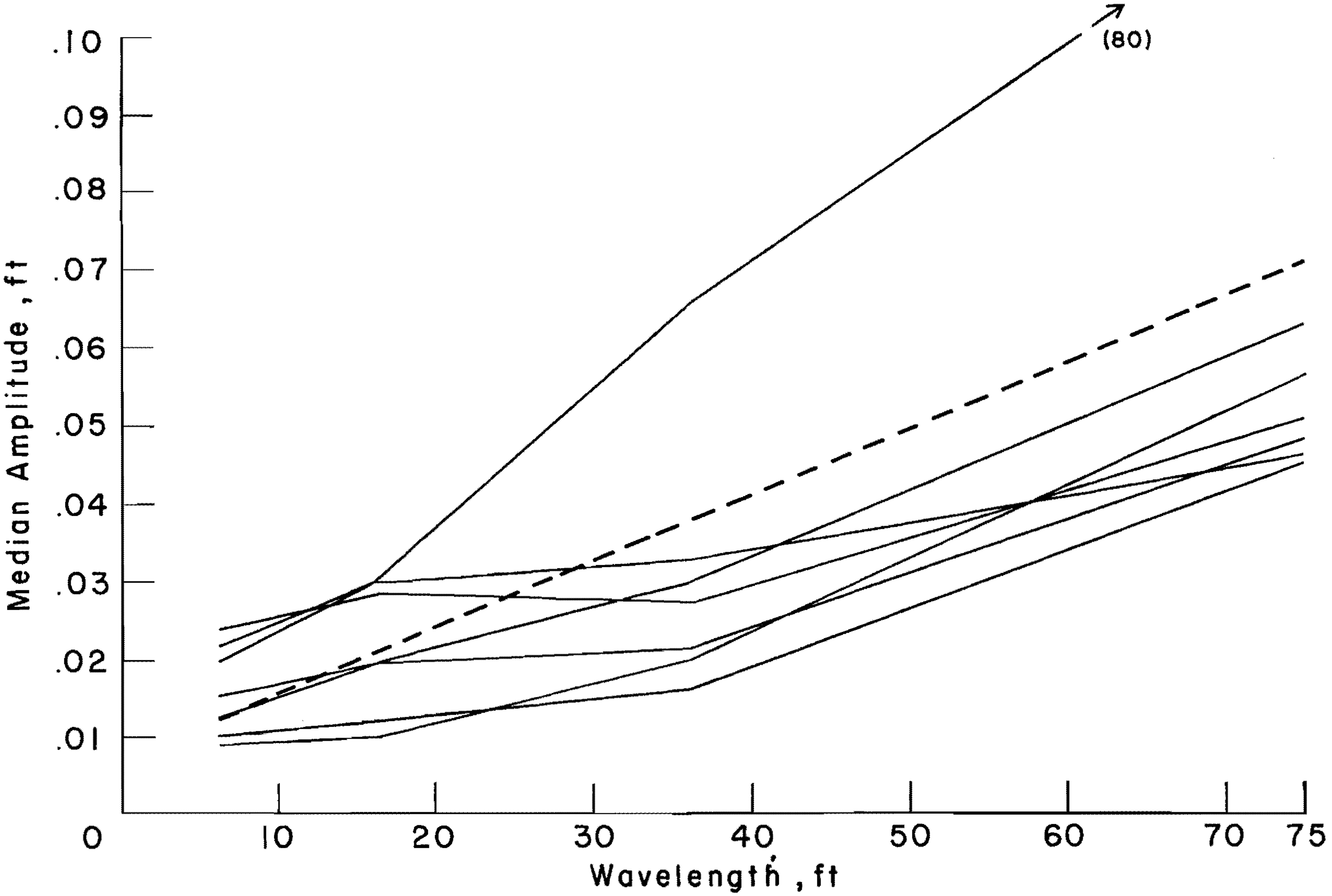


Fig 2.2 Relationship between median wave amplitude and wavelength as revealed by filtered profiles taken from seven ACP road sections near Austin, Texas. The dashed line illustrates a typical wavelength/amplitude ratio at 1000.

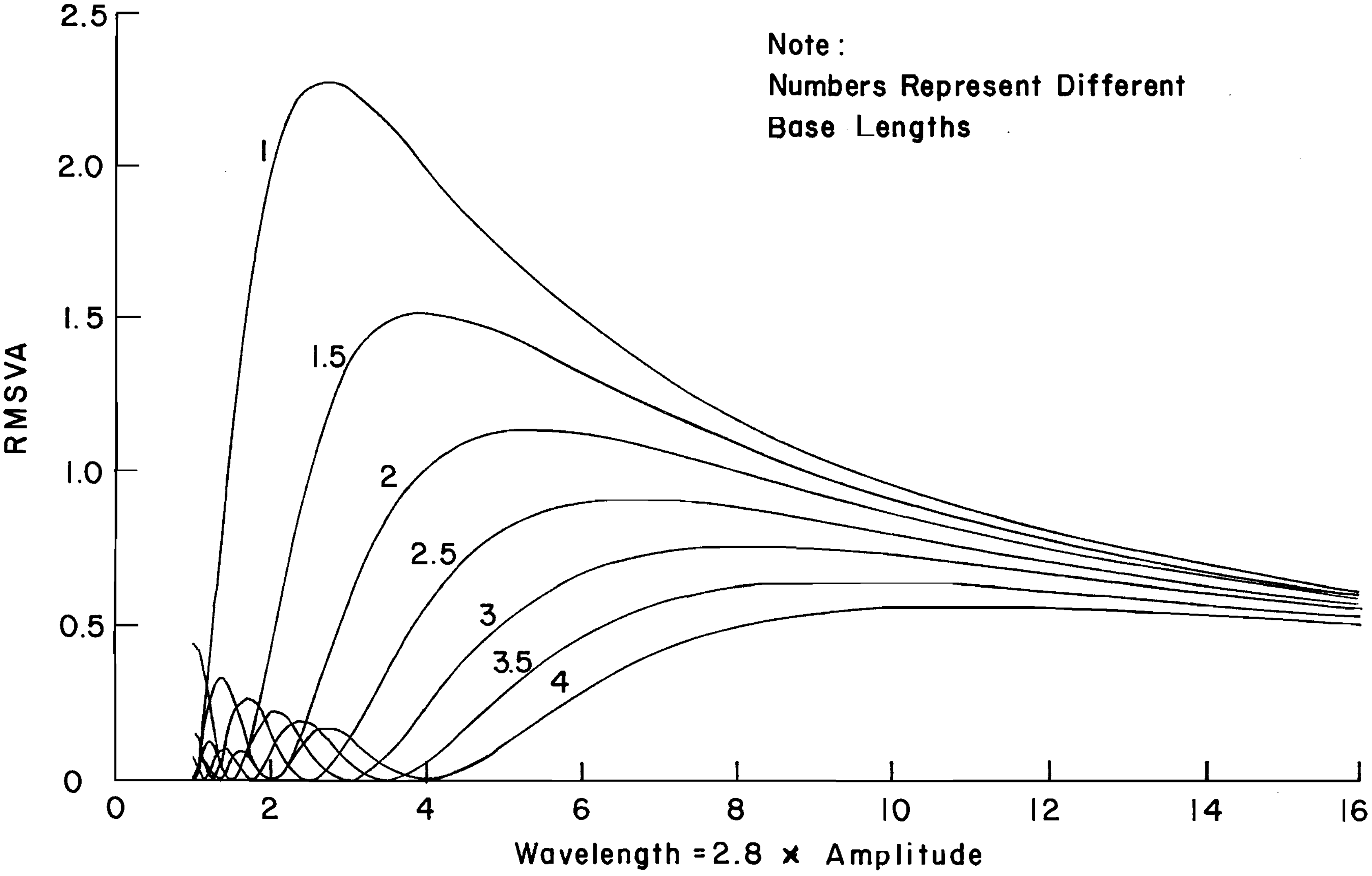


Fig 2.3. Response of RMSVA to a regular waveform at difference base lengths.

Another problem with slope variance is that the mean slope, about which variance is to be measured, is not necessarily zero in practice. Over what length of road should the mean be taken? One would not want the roughness contribution of a short road segment to depend on any (global) property of the entire road being measured. A Maysmeter is a summation device which totals axle-body displacement, a phenomenon that depends only on local roughness characteristics. RMSVA, which is a function of the differences between adjacent slopes, is likewise an averaging, or rather a root-mean-squaring, of local properties of the profile.

Although RMSVA, in a physical sense, could be related to the vertical acceleration of a tire travelling over the road (assuming base length is carefully chosen), this is not really a good characterization of its utility as a roughness measure. The Maysmeter simulation described in Chapter 3 involves only RMSVA at base lengths 4 and 16 feet. It would be better, perhaps, to think of VA_b as the root-mean-square vertical velocity of a front tire with respect to a rear tire when they are travelling b distance apart. In any case, slope variance seems to have no such mechanistic interpretation.

A ROUGHNESS CHARACTERIZATION OF THE AUSTIN TEST SECTIONS

To determine whether or not RMSVA profile indices could be specifically tailored to reveal Maysmeter-type roughness, the computer program VERTAC (Appendix B) was written to compute RMSVA for a selected sequence of base lengths. For our original correlation studies, the following indices were obtained from an October 1977 measurement of 29 ACP test sections near Austin:

$$VA_{.5},\ VA_1,\ VA_2,\ VA_4,\ VA_8,\ VA_{16},\ VA_{32},\ VA_{65}$$

The subscripts represent base length in feet, and the units are feet/sec ^{2}, as would correspond to the RMSVA of a point in contact with the road travelling 50 mph. In each case, a sampling interval of $S = 0.169$ feet was used over a section length of 1050 feet (since $S > 1/6$, the next-to-last base length is 65 feet, not 64 feet).

The small sampling interval was a characteristic of the profilometer data available to us and was not considered essential. In fact, it was found that increasing the sampling interval to 2 feet had little effect on the computed indices for baselengths 2 feet or longer. A small sampling interval simply provides more profile locations to be accounted for in the mean-square.

The above sequence of base lengths was selected in view of both the sampling interval and the observed correlation between indices. For example, it was found that the correlation between VA_2 and VA_4 was approximately the same as that between VA_4 and VA_{16}. Furthermore, the comparison with Maysmeters described in Chapter 3 shows that the sequence encompasses the smaller range of base lengths useful for predicting Maysmeter-type roughness (Fig 3.1).

The index VA_b was computed as the average RMSVA, at base length b, for the right and left wheelpath profiles. As such, the repeatability of the VA_b measurements for successive runs of the profilometer was found to be excellent. The standard errors of duplication (SE), for example, can be compared with the standard deviation (SD) of the section means (the average of 2 runs) taken over the 29 Austin test sections (Table 2.1).

TABLE 2.1. SUMMARY OF RMSVA MEASUREMENTS ON 29 ACP TEST SECTIONS

b	.507	1.014	2.028	4.056	8.112	16.224	32.448	64.849
MEAN VA_b	82.52	28.48	9.13	3.43	1.38	0.64	0.23	0.13
SD	29.71	10.56	3.73	1.77	0.86	0.43	0.19	0.075
SE	2.60	0.83	0.28	0.07	0.13	0.008	0.017	0.005

The RMSVA data for the sections reveal the important fact that variations between sections are an order of magnitude greater than variations between repeat runs. This means that, regardless of their correlations with Maysmeters, PSR, etc., the RMSVA indices represent persistent and distinguishable traits of the road sections. This is not to say that interactions between the road and profilometer system do not play a role. Bounce in the road-following wheels, for example, is believed to affect the short base-length measurements -- particularly for b = .5 feet. Such effects have been kept reasonably constant by proper maintenance of the hardware and by operating at a fixed speed of 20 mph.

The Serviceability Index SIV

Although the RMSVA indices are well defined and precisely measurable with the profilometer, they are difficult to interpret by themselves because they tend to increase rapidly in magnitude as base length decreases. The measure of riding quality with which engineers are most familiar is the Serviceability Index (SI), a number between 0 and 5. As will be described in Chapter 3, such an index, SIV, was developed based on RMSVA; however, because it was intended as a provisional calibration standard, it is a function solely of a Maysmeter simulation (inches per mile) comprised of just two RMSVA indices:

$$MO = -20 + 23VA_4 + 58VA_{16} \tag{2.7}$$

where VA_4 and VA_{16} are the mean wheelpath RMSVA at base length 4 feet and 16 feet, respectively. The serviceability estimate is calculated as

$$SIV = 5e^{-\left[\frac{ln(32MO)}{8.4933}\right]^{9.3566}} \tag{2.8}$$

and as such is a measure of roughness primarily in the 8-35 feet wavelength range.

SI Values at Different Base Lengths

SIV has proved to be an effective standard for Maysmeter calibration; however, other RMSVA indices (base lengths 2, 4, 8, 16, 32, 65, and 130 feet) are genuine roughness traits which have been useful for comparing pavements in other studies. Therefore, to make such comparisons easier, rescaled versions of these indices are usually provided which resemble a sequence of "SI_b values" in the range 0 to 5. This is accomplished simply by replacing term MO in equation (2.8) with MO_b, a linear function of VA_b obtained by a least-squares fitting of VA_b against MO:

$$
\begin{aligned}
MO_1 &= 16.16 + 2.94\ VA_1 \\
MO_2 &= -28.59 + 13.38\ VA_2 \\
MO_4 &= -23.51 + 34.46\ VA_4 \\
MO_8 &= 6.13 + 66.13\ VA_8 \\
MO_{16} &= 10.83 + 139.18\ VA_{16} \\
MO_{32} &= 10.10 + 296.66\ VA_{32} \\
MO_{65} &= 19.28 + 602.00\ VA_{65} \\
MO_{130} &= 26.30 + 1643.80\ VA_{130}
\end{aligned}
$$

The main advantage of such a scaling is that the means and standard deviations of these different SI_b values, as determined on 31 ACP test sections near Austin (April 1981), are approximately the same, making it easier to judge the significance of these measurements on particular pavements. The test sections encompass a variety of roughness conditions, exhibiting a SIV range of .63 to 4.83, with mean 3.12 and standard deviation of 1.23. For assistance in interpreting, or comparing "roughness signatures" in future studies, the results obtained during April 1980 and April 1981 on the 29 test sections are given in Appendix D.

The use of the term "SI_b" for a scaled RMSVA index is potentially misleading because the index is related to Present Serviceability Rating (PSR) in only a very indirect sense: via its correlation with SIV, which in turn is based on a study of the correlation between the Maysmeter roughness and a PSR prediction equation established during a 1968 human rating experiment. A future rating session, utilizing modern automobiles and an improved profile measuring system, should help determine the relative significance of the different roughness indices in terms of actual riding quality. In the meantime, the RMSVA summary data will be used for comparing pavements and for detecting changes in different components of roughness.

RMSVA data for two sections known to be subject to deterioration from expansive clays are shown in Fig 2.4 (SI_b plotted against base length, b), along with the corresponding values obtained periodically during the previous 18 months (dashed lines). Notice that the spectra of SI_b values form distinctive "signatures" which, in this case, changed very little during the last four-month time period. The test section (lower figure) shows the effect of treatment by a fabric moisture seal sometime prior to the first profilometer run, in June 1979. The differences, however, are confined to the longer RMSVA base lengths and would probably not be noticed in readings from a Maysmeter. Data for these sections were provided by Texas SDHPT Engineer Malcolm Steinberg.

A more typical situation is that of Austin test section No. 23 (see Appendix D), where RMSVA signatures taken one year apart show the effect of an intervening overlay on short-wavelength roughness. In this case,

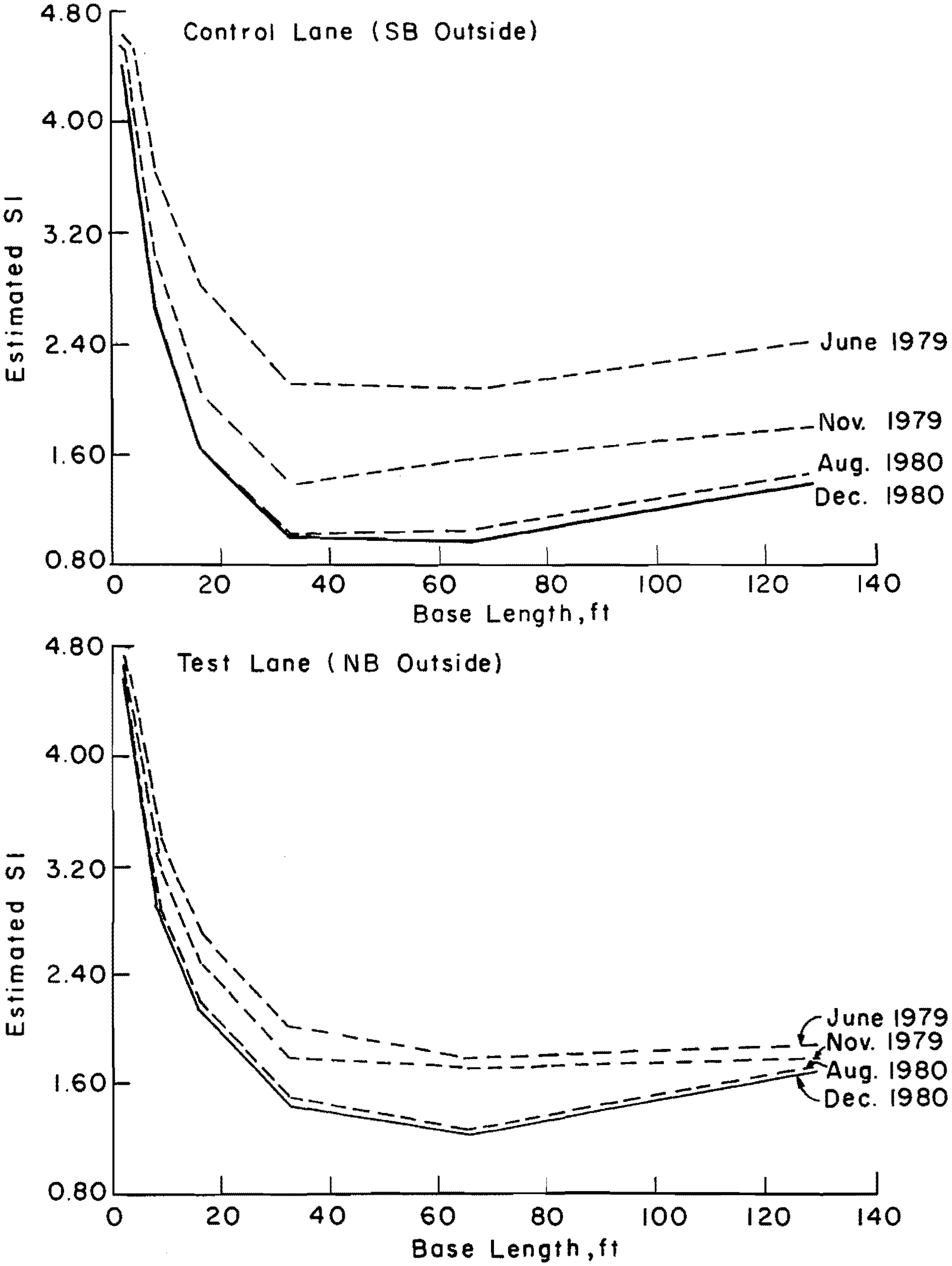


Fig 2.4. RMSVA signatures for untreated (top) and treated (bottom) ACP sections in a swelling clay environment--Loop 410, San Antonio, Texas.

Maysmeter would have detected a distinct increase in serviceability (SIV), from 2.6 to 4.0.

CHAPTER 3. DEVELOPMENT OF A MAYSMETER CALIBRATION STANDARD

While the SD Profilometer is used in Texas both for calibration and for projects requiring pavement profiles, most roughness monitoring is accomplished by a fleet of Maysmeters. Each vehicle has a chart recording system with a stepper motor that advances the chart in 1/64-inch increments, an increment corresponding to 1/10-inch vertical displacement between the vehicle's body and rear axle. Most of the Maysmeters are trailer-mounted units which are also equipped with digital readouts--32 counts per inch of chart, or five counts per inch of axle displacement. The roughness observations, in either case, are converted to units of inches of axle displacement per mile of roadway travelled. (The units "counts/.2 miles" are sometimes used and can be considered equivalent.) The road sections are normally run at 50 mph.

AN EXAMINATION OF MAYSMETER DATA

For our work in attempting to simulate the Maysmeter with road profile statistics, we had available the calibration session results for 8 devices (Table 3.1). All measurements were obtained within a month's period of an October 1977 profilometer run on 29 test sections near Austin. For convenience, the Maysmeters are labeled M1, M2, . . ., M8, with M1 through

TABLE 3.1. PROFILOMETER AND MAYSMETER DATA USED IN THE DERIVATION OF RMSVA MAYSMETER SIMULATION M0.

	RMSVA INDICES							MAYS METER MEASUREMENTS							
SEC	VA2	VA4	VA8	VA16	VA32	MO		M1	M2	M3	M4	M5	M6	M7	M8
1	7.75	2.56	1.01	.52	.30	69.0	*	---	59.0	67.5	63.0	60.0	112.5	113.8	116.0
2	11.93	5.16	2.27	.95	.46	153.8	*	173.5	144.7	185.5	145.2	170.8	244.7	249.0	309.6
5	6.28	2.53	1.00	.48	.22	66.0	*	72.3	60.3	56.0	56.8	59.3	112.3	96.8	113.6
7	3.00	1.06	.52	.30	.16	21.8	*	33.3	38.0	31.0	22.3	20.0	52.3	44.8	44.8
8	6.16	2.24	.99	.41	.17	55.3	*	65.0	64.0	60.0	53.8	59.3	92.5	92.5	88.0
9	3.90	1.45	.64	.30	.16	30.7	*	44.5	45.8	52.3	50.8	37.8	73.3	---	134.4
10	4.00	1.15	.40	.22	.14	19.2	*	29.0	38.0	24.3	18.0	22.0	53.3	43.3	36.8
11	5.83	1.75	.52	.20	.11	31.9	*	24.0	40.8	24.3	32.5	24.0	66.5	55.0	40.0
12	9.62	3.13	.95	.48	.30	79.8	*	72.0	84.5	75.5	70.0	85.3	156.3	146.5	134.4
13	11.91	3.78	1.18	.50	.23	95.9	*	98.5	100.8	113.0	98.3	122.0	211.0	189.7	187.2
14	6.00	2.01	.80	.39	.22	48.9	*	44.8	43.5	49.3	55.0	18.0	94.0	89.0	72.8
15	11.13	3.11	.93	.32	.16	70.1	*	64.8	75.5	83.0	57.5	72.3	149.8	94.0	103.2
19	6.41	2.16	.91	.53	.26	60.4	*	56.8	58.0	55.8	50.3	56.5	116.5	99.5	110.4
23	9.37	3.38	1.18	.48	.17	85.6	*	---	75.5	78.3	77.3	80.3	149.0	139.5	164.8
28	4.04	1.50	.75	.42	.19	38.9	*	---	43.5	41.3	44.8	38.8	80.0	72.8	73.6
32	9.40	2.82	.94	.37	.22	66.3	*	51.3	52.8	50.0	43.8	37.0	117.3	84.5	84.0
33	7.61	3.37	1.50	.65	.26	95.2	*	102.2	88.3	118.2	98.3	106.0	162.0	125.5	165.6
34	8.91	3.33	1.25	.50	.23	85.6	*	89.5	81.8	94.0	74.3	85.0	142.5	143.8	144.0
35	14.37	6.58	2.20	.98	.39	188.2	*	198.7	178.0	195.8	164.3	201.8	---	---	406.4
36	6.58	1.78	.55	.27	.08	36.6	*	25.8	24.3	22.3	19.3	24.5	95.0	43.3	35.2
37	9.84	3.18	1.03	.41	.21	76.9	*	87.5	84.8	74.8	70.8	76.5	168.5	146.5	---
38	14.53	4.28	1.17	.45	.22	104.5	*	112.7	114.5	142.0	117.8	113.5	---	---	221.6
39	11.77	5.08	2.35	.92	.37	150.2	*	143.5	138.5	159.0	131.8	130.7	223.0	220.5	279.2
40	7.67	2.34	.83	.45	.29	59.9	*	64.5	63.5	71.8	67.3	50.3	93.0	100.2	93.6
41	11.92	4.37	1.74	.77	.30	125.2	*	139.7	123.2	133.0	121.3	133.3	194.5	182.7	207.2
42	16.63	7.74	3.14	1.23	.44	229.4	*	229.8	212.5	235.5	224.5	230.7	---	---	368.8
43	16.91	6.55	3.07	1.45	.71	214.7	*	223.7	216.8	227.2	218.0	223.5	---	---	404.8
44	10.18	4.88	2.73	1.67	.85	189.1	*	202.0	179.0	192.3	154.0	201.0	---	---	376.6
45	11.19	6.09	3.44	1.86	.83	227.9	*	259.2	188.8	241.8	223.0	241.5	---	---	419.2

M5 denoting the trailer-mounted units. Each table entry was obtained by averaging the results of four runs on a 0.2-mile section. (A fifth run, which had deviated most from the overall mean, was first excluded.) This redundancy provides a measure of the repeatability of the Maysmeter for successive runs. Table 3.2 contains the average section mean, the standard deviation of the section means, SD, and the standard error of repeatability, SE, for each unit. The repeatability (although underestimated slightly because of the excluded value) is quite good considering that 100 ± 5 in./mile corresponds roughly to a Serviceability Index of 2.7 ± 0.1.

TABLE 3.2. MRM RESULTS - OCT - DEC 1977

	M1	M2	M3	M4	M5	M6	M7	M8
MEAN	104.17	93.73	101.87	90.46	95.91	128.67	116.96	174.02
SD	70.13	56.02	67.83	60.05	69.16	54.17	56.34	125.27
SE	5.01	3.88	6.47	3.94	7.19	6.33	7.27	16.05

Most relevant to the problem of calibration are the relationships shown to exist among the different units. The correlation matrix for the data in Table 3.1 indicates that the Maysmeter roughness readings are highly correlated and, in fact, plots show that the relationships are linear. If we were to seek a simple linear calibration function, with one of the units selected as the reference device, then a good choice of reference would be unit M3, whose measurements explain a high percentage of the section-to-section response variation in the other units. Specifically, the coefficients of determination (R^2) and the standard errors of estimate (SE) for the model

$$Mi = \alpha_i + \beta_i \, M3 + \varepsilon_i \tag{3.1}$$

are:

	M1	M2	M4	M5	M6	M7	M8
R	.975	.970	.976	.974	.857	.900	.964
SE	11.3	10.0	9.4	11.4	21.0	18.3	24.3

Each of the other trailer units would serve about equally well as a standard reference. The car units M6, M7, and M8 behave less predictably (there are no measurements on the rough sections for the first two), although trailer unit M3 explains their response about as well as any one car would explain the other two cars.

Such close agreement between the different units over a two-month period convinced us that a linear calibration model such as Eq 3.1 would be adequate provided we could find a profile statistic that could effectively assume the role of M3. Unlike M3, of course, it should also have long-term stability, depending only on the profilometer or other instruments to obtain a reasonably accurate profile. Moreover, since calibration requires that measurements from all units be transferable to a common scale, we cannot hope to find a single statistic that agrees much better with the units than they do between themselves; hence, we can be satisfied if our candidate statistic performs about as well as M3 above. This means that standard errors of estimate (SE) should be on the order of 10 in./mile or 0.2 units of serviceability. This would be a significant improvement, incidentally, over the 0.5 or 0.6 unit SE typically obtained in a calibration based on the serviceability index (SI), a method once used by the Texas State Department of Highways and Public Transportation (Eq 2.1).

CORRELATION OF THE MAYSMETER WITH RMSVA

A comparison of Maysmeter data with the RMSVA indices of Table 2.1 reveals significant individual correlations with the subset VA_2, VA_4, VA_8, VA_{16}, and VA_{32} (Table 3.3), and plots show that the relationships are essentially linear. Also, the replication errors for the Maysmeters do not seem to be significantly larger for the rougher sections. Therefore, no transformation or weighting was considered necessary when forming the regression models.

If we were to choose a single RMSVA index to explain the Maysmeter results then it would be VA_8. For example, when the San Angelo Unit M1 is regressed on VA_8 we obtain

$$M1 = 5.1 + 76.7\ VA_8 ,$$

$$R^2 = .964,$$

$$SE = 13.6.$$

TABLE 3.3. INDIVIDUAL CORRELATIONS BETWEEN MRM AND RMSVA INDICES

RMSVA	M1	M2	M3	M4	M5	M6	M7	M8
VA2	0.794	0.858	0.841	0.834	0.829	0.917	0.843	0.820
VA4	0.953	0.970	0.964	0.962	0.960	0.971	0.954	0.955
VA8	0.982	0.963	0.968	0.971	0.964	0.889	0.917	0.961
VA16	0.945	0.904	0.909	0.911	0.920	0.831	0.887	0.924
VA32	0.879	0.840	0.839	0.836	0.848	0.721	0.820	0.862
MO	0.991	0.986	0.984	0.983	0.986	0.955	0.962	0.984

Given the similar results for M2 - M8 (M6 correlates better with VA_4 than with VA_8) we find that VA alone is a much better predictor of Maysmeter response than the serviceability index used previously for calibration.

On the other hand, plots of $VA_{.5}$ and VA_{65} versus Mi showed little or no correlation between Maysmeters and RMSVA at those base lengths. Although $VA_{.5}$ and VA_{65} are genuine characteristics of the sections, as Table 2.1 shows, the Maysmeters are simply not sensitive to those characteristics. (Actually, $VA_{.5}$ is more an interaction between the road and measuring system, in which bounce of the profilometer's following wheels plays a role.)

When multiple regression procedures were applied to the Maysmeter data, it was found that two indices, VA_4 and VA_{16} , were sufficient to explain quite well the variations between Maysmeters on the 29 test sections. Furthermore, no significant improvement in the correlations came about by allowing different combinations, or functions, of RMSVA indices. Figure 3.1 shows that the correlations of the two indices VA_4 and VA_{16} with Maysmeter roughness are large compared with their correlation with each other; hence, each statistic contains relevant information that is not contained in both statistics. Such plots actually indicate that the peak response for most Maysmeter units is at a base length smaller than 8 feet and that another pair, say VA_3 and VA_{12} , might have provided marginally better correlations.

Comparison of the Maysmeter data with VA_4 and VA_{12} produced the following regression equations:

$$M1 = -20.1 + 20.9VA_4 + 77VA_{16}, \qquad R^2 = .98$$

$$M2 = -9.4 + 22.4VA_4 + 42.2VA_{16}, \qquad R^2 = .97$$

$$M3 = -22.1 + 25.9VA_4 + 55.3VA_{16}, \qquad R^2 = .97$$

$$M4 = -18.9 + 22.4VA_4 + 63.9VA_{16}, \qquad R^2 = .97$$

$$M5 = -29.4 + 24.7VA_4 + 63.9VA_{16}, \qquad R^2 = .97$$

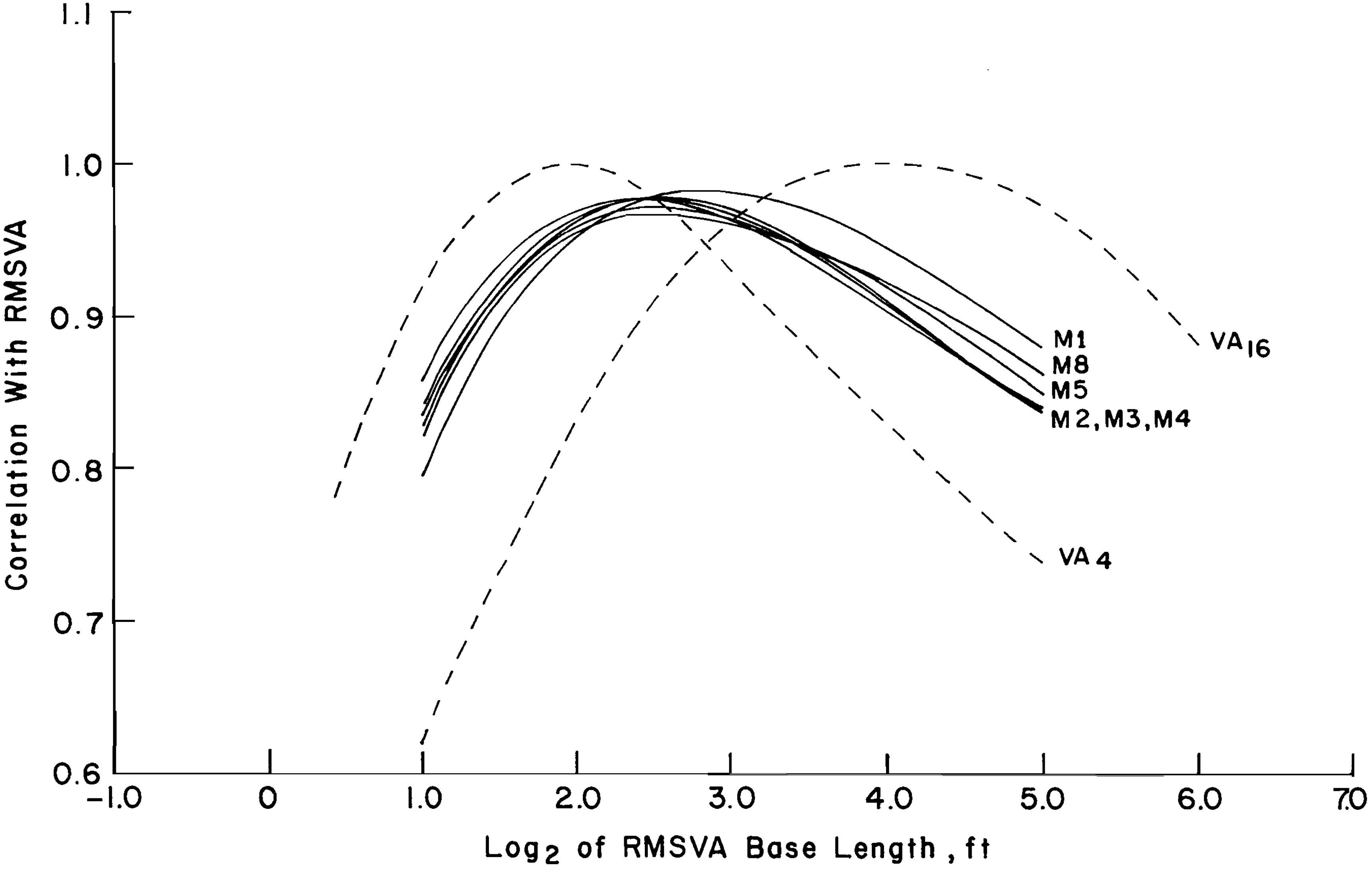


Fig 3.1. Correlation of Texas Maysmeter measurements with RMSVA.

. . . .

$$M6 = 2.5 + 48.1VA_4 - 12.8VA_{16}, \quad R^2 = .94$$

$$M7 = -20.8 + 36.8VA_4 + 71.8VA_{16}, \quad R^2 = .93$$

$$M8 = -41.7 + 40.2VA_4 + 123.9VA_{16}, \quad R^2 = .97$$

The quality of fit is illustrated by the plotted results for M1 in Fig 3.2. The equations for the trailers are strikingly similar, whereas the three car-mounted Maysmeters comprise a more divergent group. The decision was made to tailor the calibration standard to the more numerous trailers, because of their superior performance and the likelihood that such a standard would serve the cars about as well as one developed specifically for them.

One might suppose that a calibration procedure could be based on an equation of the form

$$Mi = \alpha_i + \beta_i VA + \gamma_i VA_{16} \tag{3.2}$$

with α_i , β_i , and γ_i serving as the parameters to be adjusted for unit i . This might allow adjustments for more than one operating speed. (A reduced speed, for example, would lessen the relative importance of the longer base length.) Our goal, however, is not to simulate a particular Maysmeter run at an arbitrary speed, but to obtain a calibration model that can serve to scale different units so they are compatible with an accepted standard. Such models cannot contain two explicit profile variables, for the simple reason that, in converting a particular unit's measurement to what a "standard device" would obtain, we would face the impossibility of deriving two unknowns, in this case VA_4 and VA_{16}, from a single quantity.

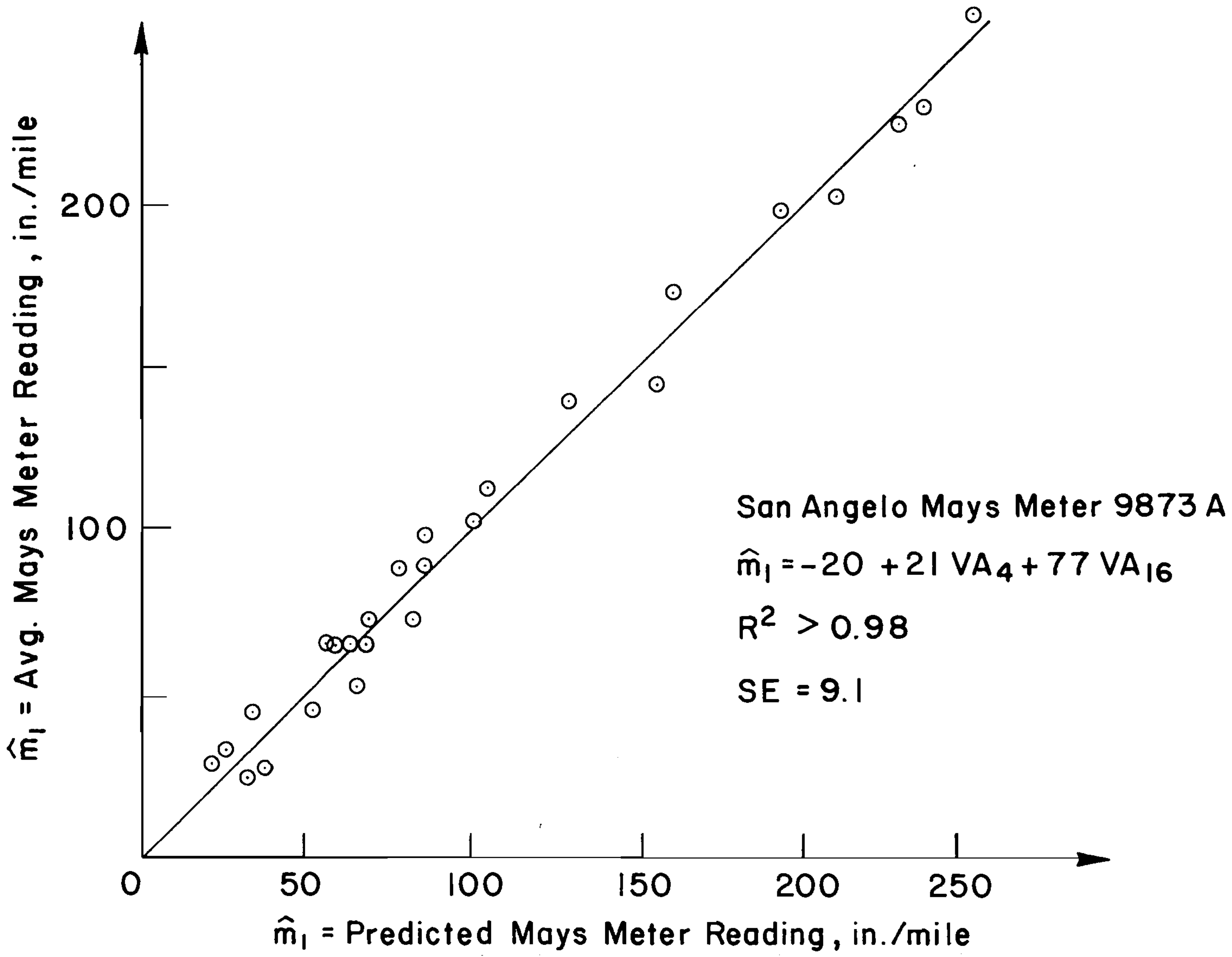


Fig 3.2. A prediction equation for the San Angelo Maysmeter based on RMSVA statistics VA_4 and VA_{16}.

The method we chose, which is justified by the marked similarity of the above regressions, is to fit Mi (run at the standard speed of 50 mph) to

$$\text{Mi} = \alpha_i + \beta_i (VA_4 + R\ VA_{16}) \tag{3.3}$$

where R is predetermined to provide an optimum calibration for the collection of Maysmeter trailers as a whole. This nonlinear regression problem is easily solved by plotting the total regression sum of squares for Eq 3.3 at various values of R and interpolating the minimum. In this manner, $R \simeq 2.5$ was obtained.

Such considerations led us, finally, to the calibration model

$$\text{Mi} = \alpha_i + \beta_i \text{MO} + E_i \tag{3.4}$$

where

$$\text{MO} = -20 + 23VA_4 + 58VA_{16} \tag{3.5}$$

The coefficients in the RMSVA statistic, MO, were selected so that α_i and β_i are approximately 0 and 1, respectively, for the Maysmeter trailers. Thus, MO will serve as our simulated Maysmeter. The results of fitting model 3.4 to the Maysmeter and RMSVA data (Table 3.1) are given in Table 3.4.

TABLE 3.4. REGRESSION RESULTING FROM FITTING EIGHT MAYS METERS TO THE LINEAR MODEL OF EQUATION 9

	M1	M2	M3	M4	M5	M6	M7	M8
α_i	-1.7	9.6	0.2	0.5	-7.9	28.6	8.9	-11.9
β_i	1.07	0.88	1.06	0.94	1.08	1.42	1.49	1.93
R^2	.981	.972	.969	.967	.972	.913	.925	.968
SE	9.7	9.5	12.2	11.1	11.9	16.4	15.8	22.8

A comparison of these results with those of the 3-term model (3.2) shows that little is lost by adopting a fixed combination of VA_4 and VA_{16}, even if our purpose were not calibration but actual prediction of a particular Maysmeter's behavior. More important, M0 is at least as successful in describing the Maysmeter data as is any one of the units themselves, including M3, which it most closely resembles. (This conclusion is supported not only by data used in the development of M0 but by subsequent analyses of new data.) Furthermore, when plots of Mi versus M0 are compared, the scatters about the regression lines are dissimilar; that is, what is not explained by M0 is also not explained by another Maysmeter in terms of linear relationships.

The regression results of Table 3.4 are illustrated graphically in Fig 3.3, which shows the relationships among the eight Maysmeters we examined. Although the conclusion is based on less data, the car-mounted Maysmeters obviously differ from the trailers in their relationship to M0. The five trailers, however, are so similar in their response that they would seem to be indistinguishable and thus be in no need of calibration. Yet,

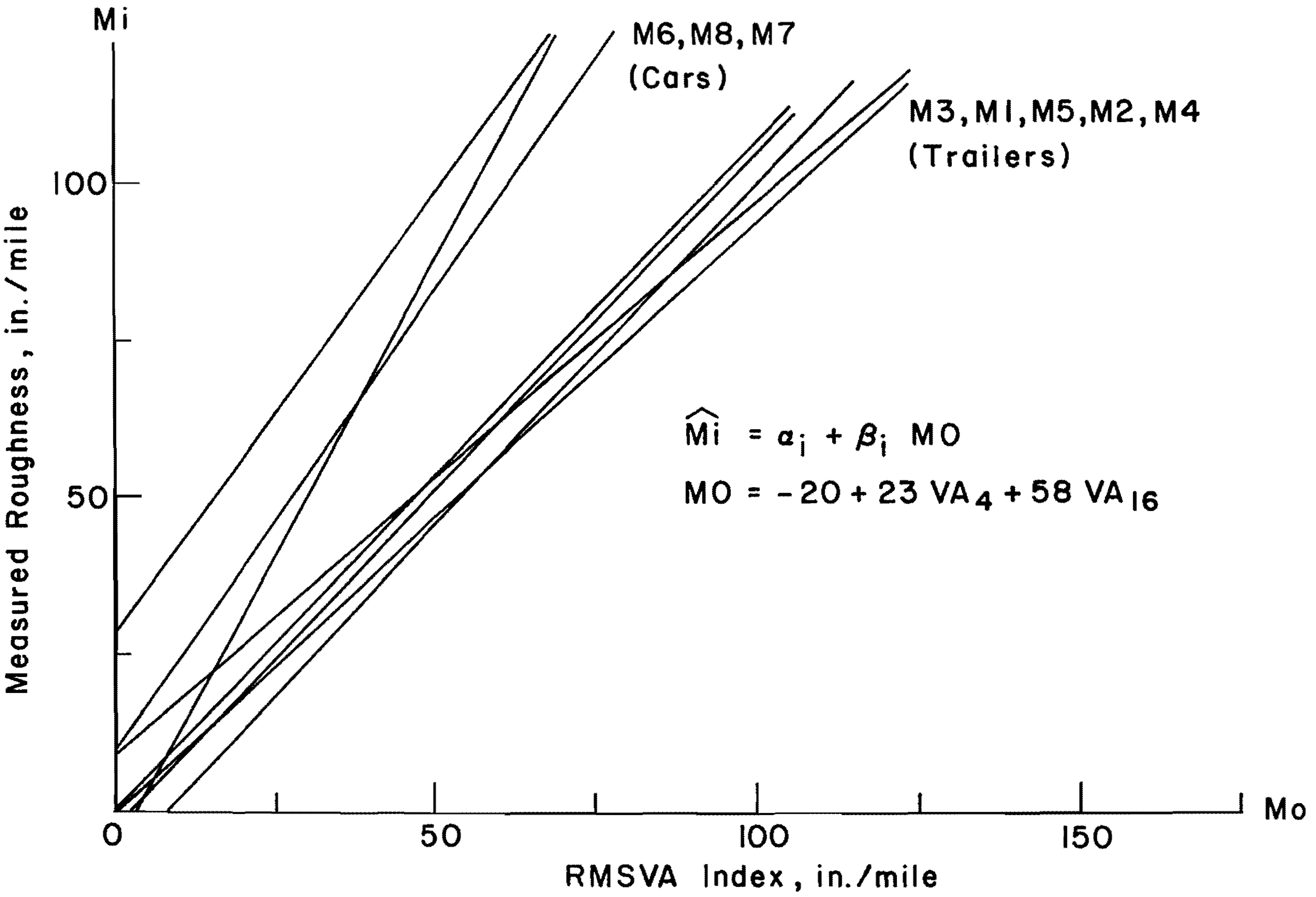


Fig 3.3. Calibration session results for eight Texas Maysmeters.

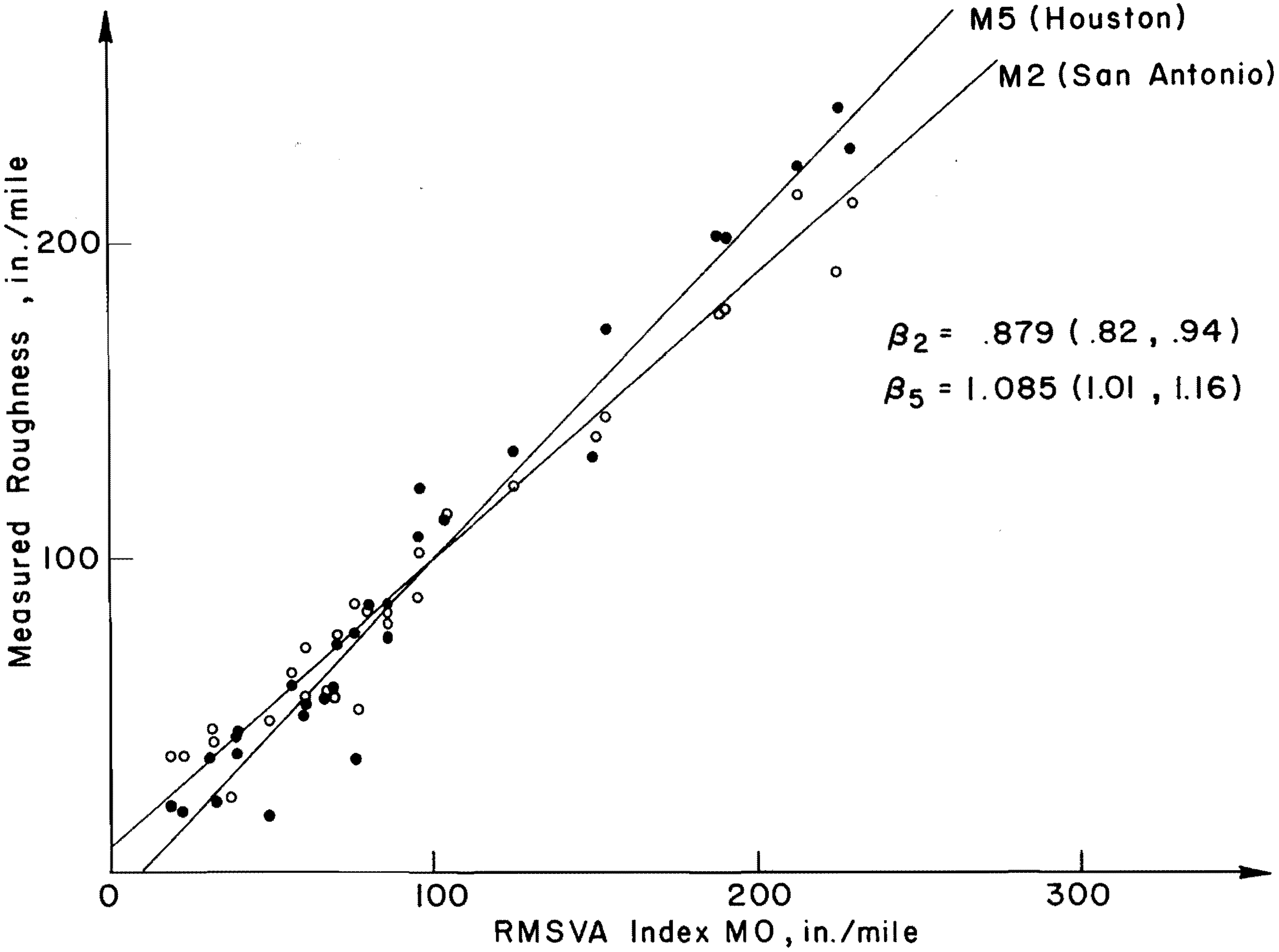


Fig 3.4. Calibration results for two trailer-mounted Mays Meters: 95% confidence intervals for calibration parameters B_2 and B_5 are given.

their correlation with M0 is strong enough that units as similar to each other as M2 and M5 can be separated, as is shown in Fig 3.4. Ninety-five percent confidence intervals for their slope parameters (B_2 and B_5) do not, in fact, overlap.

Several of the pavement test sections we examined had one wheelpath with a profile significantly rougher than that of the other wheelpath. It is important that measurements of both wheelpaths be obtained, for we found that the procedure of averaging the RMSVA indices from two wheelpaths resulted in an index that correlated much better with the Maysmeters than did any single-wheelpath index. We believe that simply averaging the two wheelpath indices is preferable to including a summary statistic based, for example, on the "difference profile," for the latter method would make it difficult to use one wheelpath profile when that of the other wheelpath, for some reason, is not available. The discrepancy between wheelpaths is usually much smaller than that between different road sections, and, when exceptions have occurred, a simple average usually has succeeded in aligning with the calibrated Maysmeter's results.

We summarize the Maysmeter/RMSVA correlation study as follows: a profile statistic based on RMSVA at base lengths 4 ft and 16 ft was successful in explaining approximately 97 percent of the response variation between five trailer-mounted Maysmeters on 29 ACP pavement test sections. This corresponds to a prediction standard error of about 10 percent of the Maysmeter reading (inches/mile), which compares favorably with what would be achieved if an actual Maysmeter were singled out as the reference device (Eq 3.1). Results for the three Maysmeter cars were not quite as favorable (R^2 = .91, .93, and .95); however, data for two of the cars were incomplete.

The correlation studies which produced the profile statistic MO (Eq 3.5) were carried out in early 1978 and since then the statistic has been used regularly by the Texas State Department of Highways and Public Transportation for calibrating their Maysmeters. Although MO was "tailored" to describe Maysmeter data obtained in November 1977, subsequent Maysmeter calibrations have continued to demonstrate the high correlations described above.

The Linear Calibration Model

The general problem of calibration in which one has N pairs of observations, say (x_i , y_i), $i = 1, . . . , N$, where x_i is precise and expensive to obtain while y_i is relatively imprecise and less expensive to obtain, has been given considerable recent attention by statisticians (see, for example, Scheffe, Ref 15). Much of the discussion has dealt with the relative merits of Classical linear calibration, where one fits the N observation pairs to the model

$$y_k = \alpha + \beta x_k + \varepsilon_k \ , \qquad k = 1, . . . , N \qquad (3.6)$$

and estimates a future x by

$$\hat{x} = (y - \hat{\alpha})/\hat{\beta} \ ,$$

and inverse linear regression, where one assumes

$$x_k = a \_ by_k + e_k \ , \qquad K = 1, . . ., N \qquad (3.7)$$

and regresses x on y to obtain the prediction equation

$$x = \hat{a} + \hat{b}y \quad .$$

We have chosen the former method, primarily because it is customary to regard the independent variables in a regression model as being precisely known and usually causal to the dependent variable or response. Although we will eventually convert a calibrated unit's measurement Mi to a serviceability estimate by way of

$$\hat{MO} = (Mi - \alpha_i)/ \beta_i$$

the fact that β_i is approximately one tends to minimize the distinction between the classical and inverse approaches.

Furthermore, it is advantageous to obtain precise calibration parameters α_i and β_i based on model 3.6 if one is interested in detecting physical changes in units. The calibration regression lines for the eight Maysmeters (Fig 3.3) might suggest that the trailer units, M1 - M5, would be nearly indistinguishable. Yet, the quality of the model is such that units quite similar to each other can be separated (Fig 3.4) and the effects of wear or parts replacement in single units can be detected.

TABLE 3.5. SERVICEABILITY RATING OF AUSTIN TEST SECTIONS

SEC	SI2	SIV
1	3.20 (.08)	2.64 (.01)
2	1.14 (.15)	1.16 (.01)
3	3.77 (.04)	3.75 (.06)
5	4.28 (.13)	4.66 (.02)
6	3.17 (.03)	2.59 (.09)
7	4.56 (.27)	4.83 (.01)
8	3.75 (.01)	3.54 (.02)
9	3.31 (.02)	3.15 (.01)
10	4.71 (.12)	4.46 (.00)
12	3.57 (.38)	2.25 (.07)
13	3.19 (.02)	2.50 (.01)
14	3.53 (.26)	3.42 (.08)
15	3.92 (.13)	3.69 (.00)
19	3.84 (.04)	3.42 (.02)
23	3.21 (.02)	2.64 (.01)
28	4.09 (.09)	4.12 (.02)
35	1.37 (.05)	1.11 (.00)
36	4.43 (.02)	4.33 (.02)
37	3.19 (.25)	2.45 (.08)
38	3.21 (.06)	2.03 (.01)
39	.41 (.16)	1.03 (.00)
40	3.41 (.11)	3.56 (.02)
41	2.01 (.01)	2.07 (.00)
43	2.06 (.01)	1.71 (.01)
44	2.57 (.02)	1.18 (.00)
45	.65 (.15)	.38 (.00)
MEANS:	3.10	2.79
SD:	1.17	1.24
REPEATABILITY:	.198	.049

Field Performance

The RMSVA statistic M0 has yet to be employed directly for calibration of Texas Maysmeters. However, for the year beginning April 1978 two types of profile-derived serviceability estimates, SI2 and SIV, were supplied quarterly for use in the nonlinear calibration model (Eq 2.1). SI2 is the index based on power spectral estimates while SIV is derived by submitting the simulation M0 to the same nonlinear regression on SI2, as if it were actual Maysmeter. Hence, SIV is simply a rescaling of M0 so that its values resemble a serviceability index ranging from 0 to 5. The profilometer results for April 1979, which are typical, are summarized in Table 3.5. The standard errors of repeatability, as determined from the pairs of runs, are .16 and .05 for SI2 and SIV, respectively. The overall means and standard deviations for the section measurements, however, are essentially the same for both indices.

A plot of the Houston unit's measurements (M5) versus SI2 (Fig 3.5), shows that the calibration method introduced in 1973 had deteriorated to the extent that a nonlinear relationship between SI2 and M5 could not be detected. Figure 3.6 shows the effect of simply replacing SI2 with SIV. Such improvement has been typical of the calibrations that have taken place since early 1978. Figures 3.7 and 3.8 show results for the same unit when calibrated on a somewhat changed set of sections about 15 months later. In this case, SI (predicted from the regression) is plotted against each of SI2 and SIV. Figure 3.7 clearly reveals the relative insensitivity of SI2 to properties of the rougher pavements. Again, replacement of SI2 with SIV (Fig 3.8) improves the fit dramatically and results in a more effective calibration.

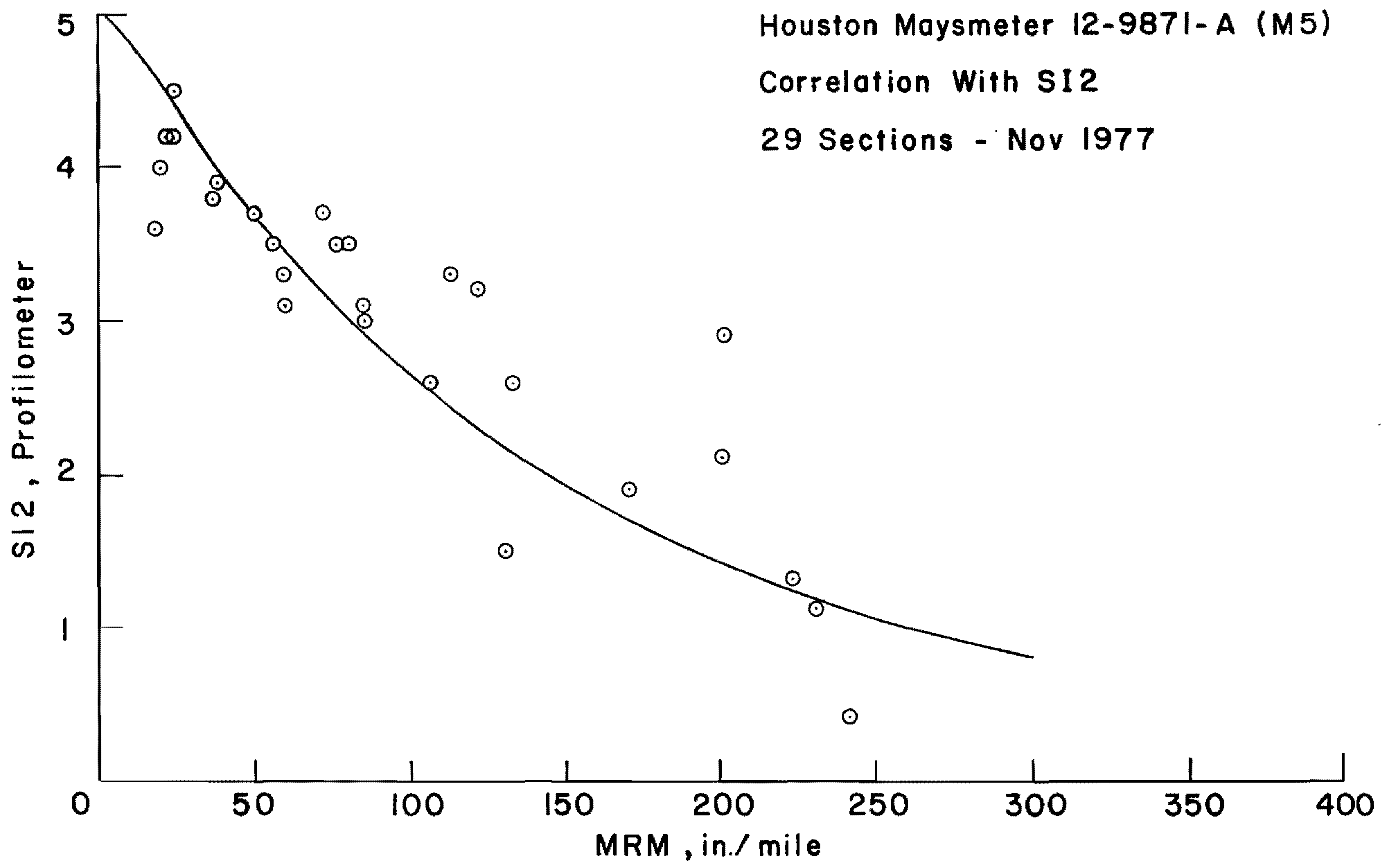


Fig 3.5. Calibration session results for Maysmeter M5 with statistic SI2 employed as the standard.

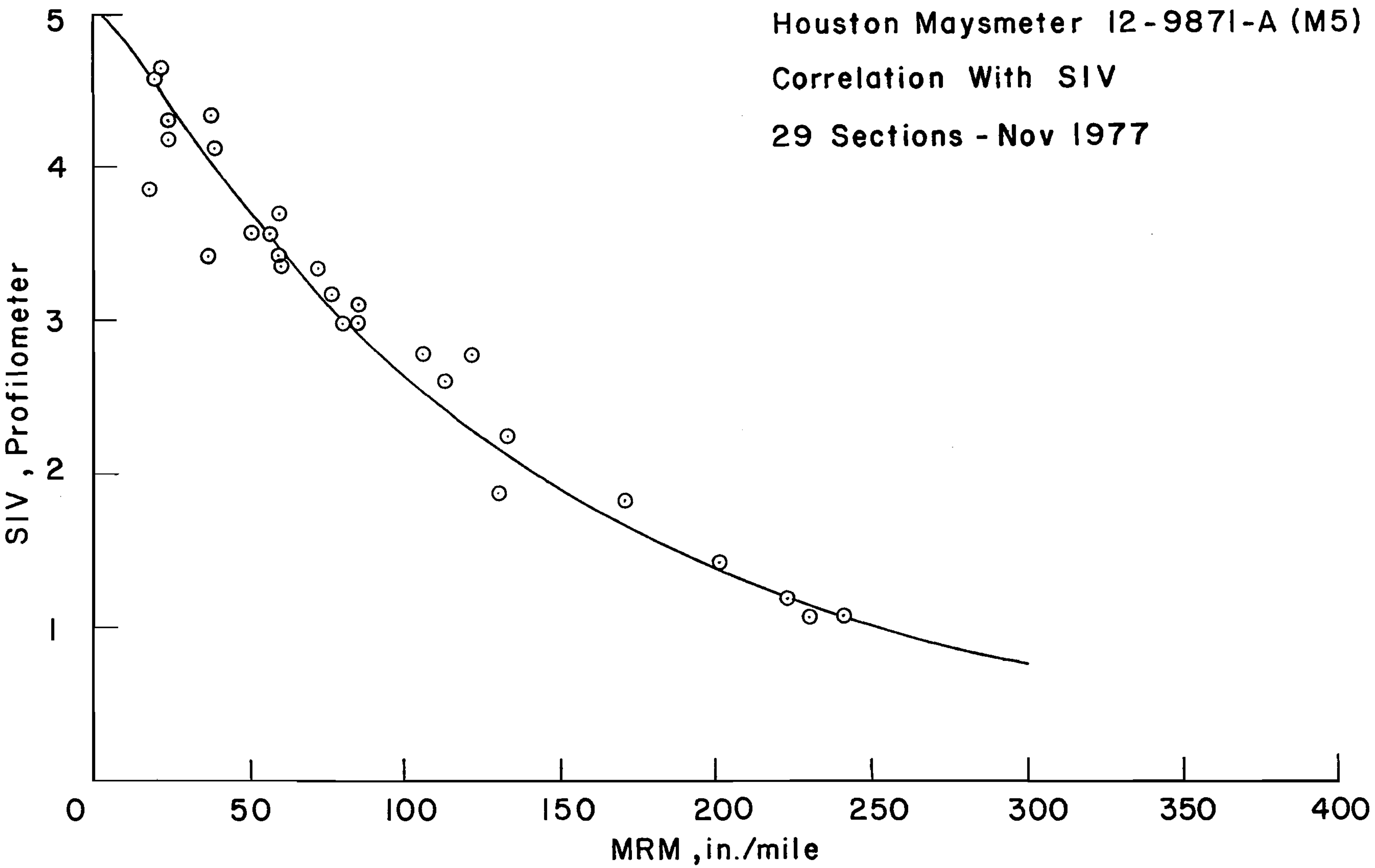


Fig 3.6. Calibration session results for Maysmeter M5 with RMSVA statistic SIV employed as the standard.

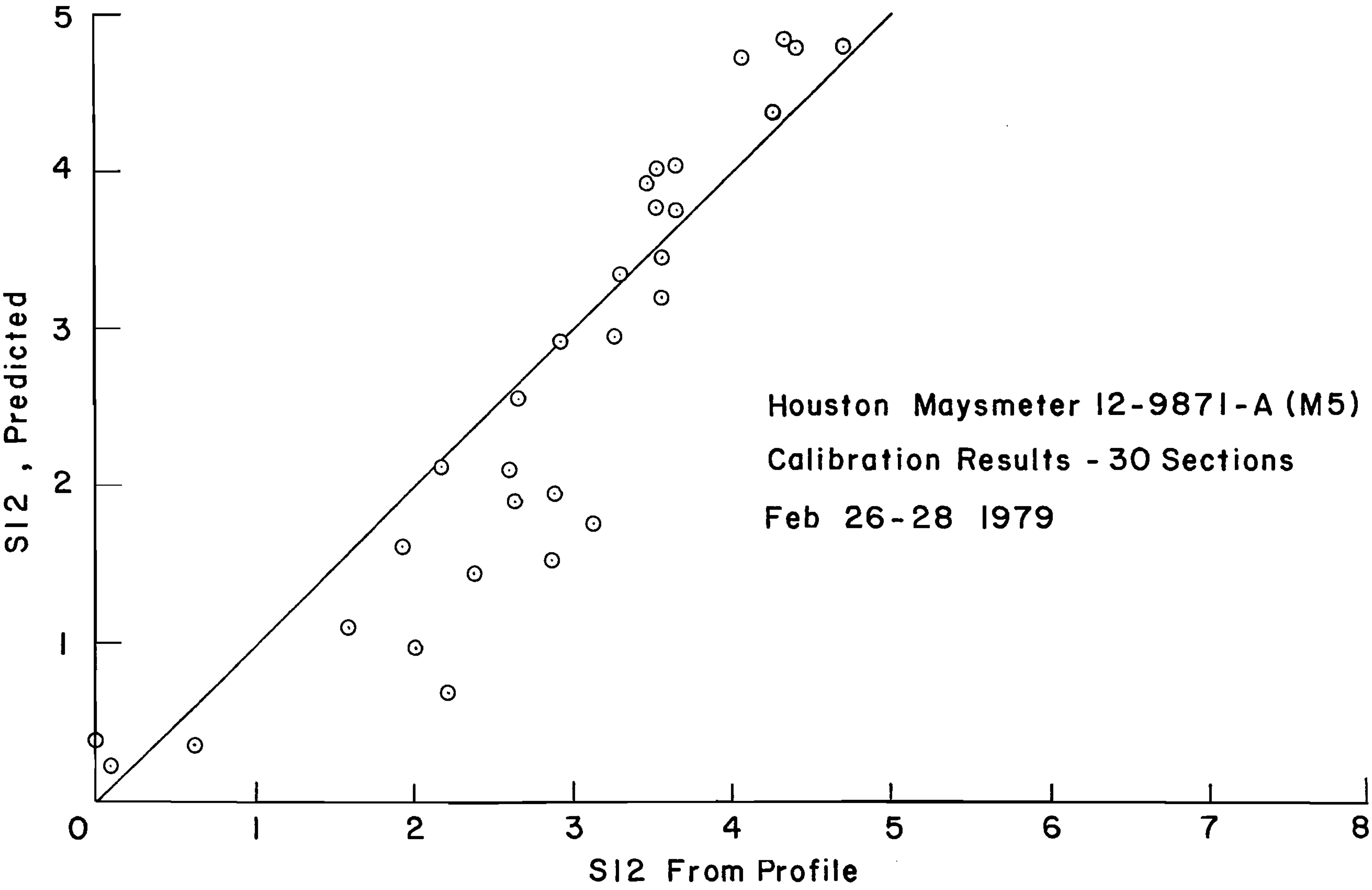


Fig 3.7. Residual plot of calibration session results for Maysmeter M5 with statistic SI2 employed as the standard.

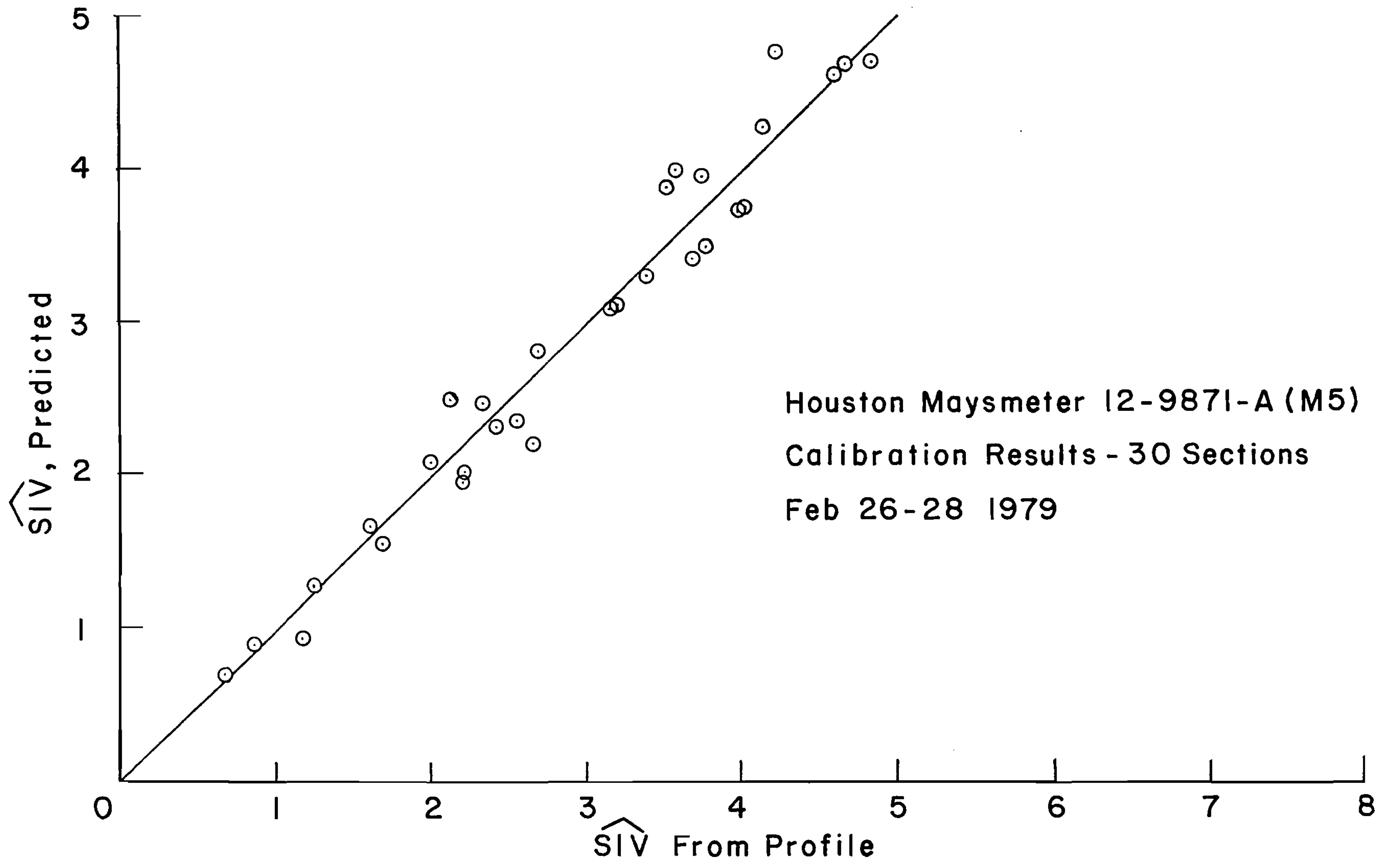


Fig 3.8. Residual plot of calibration session results for Maysmeter M5 with RMSVA statistic SIV employed as the standard.

CHAPTER 4. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

RECOMMENDATIONS REGARDING THE TEXAS MRM CALIBRATION PROCEDURE

In Chapter 3, we outlined the development of a road profile statistic, MO, which effectively models the Texas Maysmeters. A particular Maysmeter unit i is thus described simply by

$$Mi = \alpha_i + \beta_i \, MO + e \qquad (4.1)$$

where Mi is its reading (inches/mile), MO is the (RMSVA) profile statistic, and α_i and β_i are parameters (approximately 0 and 1, respectively, for the Maysmeter trailers). The random error e has a standard deviation of approximately 10 in./mile, which is comparable to Maysmeter repeatability for successive runs and is about 15 percent of the standard deviation of MO over the Austin test sections.

It is recommended that the SDHPT procedure for Maysmeter calibration be fully revised to incorporate the improved calibration standard. Outlined on the next page are (a) the old method, which employs the original version of calibration regression program MRMCAL, (b) the recommended method, which entails use of the revised program MRMCAL2 and a change in the form of the equation that converts Mi to a serviceability index, and (c) the provisional method, which entails no changes in procedure but requires simply the replacement of the old standard SI2 with the MO-derived SIV.

Old Method

When a Maysmeter unit is calibrated on the test sections, the nonlinear regression program MRMCAL computes α_i and β_i such that Mi can be converted to serviceability indices $\widehat{SI2}$ by the equation

$$\widehat{SI2} = 5e^{-\left[ln(32Mi)/\beta_i\right]^{\alpha_i}} \qquad (4.2)$$

Mi is scaled by 32 because MRMCAL expects input in units of chart inches. The program was never revised to accept counts, or in./mile, directly because it was felt that the adjustment of parameters α_i and β_i would account for the different kinds of units. The standard error of this estimate (from the regression on profilometer SI2 values) is typically 0.5 or greater. In addition to α_i and β_i , MRMCAL provides a calibration table relating SI2 to Mi.

Recommended Method

The revised calibration program, MRMCAL2, performs the simple linear regression as indicated in Eq 4.1 and calculates parameters and for converting Mi to the "standard MRM roughness index" MO:

$$\widehat{MO} = (Mi - \alpha_i)/\beta_i$$

The corresponding serviceability index is then

$$SIV = 5e^{-\left[\frac{ln(32\ MO)}{\beta_0}\right]^{\alpha_0}} \qquad (4.3)$$

The parameters α_0 and β_0 will have been derived independently of any particular MRM and thus behave as constants. The new program prints a three-way table relating Mi, $\widehat{MO}$, and SIV. Other output includes confidence intervals for the parameters α_i and β_i, regression statistics SE and R^2, and a plot of Mi vs $\widehat{MO}$.

Provisional Method

The new MRM standard MO was devised in early 1978. To test its effectiveness without changing existing procedures a relationship was established between it and SI2 by "calibrating" it via the old method, as if it were an actual Maysmeter. This resulted in the serviceability index,

$$SIV = 5e^{-\left[\frac{ln(32\ MO)}{8.4933}\right]^{9.3566}} \qquad (4.4)$$

Hence, the provisional method is simply to let the profile-derived SIV play the role of SI2 in the old method. While it is a definite improvement with respect to bringing different MRM units into alignment (standard errors of estimate are less than half as great), it should be replaced as soon as possible by the more direct linear method employing the revised MRMCAL2 (Appendix C).

SUMMARY OF RESULTS FOR THE AUSTIN TEST SECTIONS

For the year beginning January 1978, both SI2 and SIV were recorded for the quarterly profilometer runs on the Austin test sections. The results are listed in Tables 4.1 and 4.2. Each measurement is actually the mean of two separate runs, with differences between repeats being at least three times larger for SI2 than for SIV. The SI2 results were also more erratic over the time period. Seventy percent of the variation of SIV about the means of 19 relatively unaltered sections could be explained by linear declines whereas only 42 percent of SI2 variation could be so explained. These facts suggest that the simpler statistic SIV, while correlating much better with Maysmeters, is also less sensitive to the measuring system and factors not related to the actual profile. Interestingly, the mean decline for these 19 sections over one year was only 0.22 serviceability units, which is comparable to the discrepancy between repeated SI2 measurements with the profilometer.

BENEFITS OF THE RECOMMENDED METHOD

In summary, the advantages of adopting the procedures described in Chapter 3, which employ statistic MO instead of SI as the Maysmeter calibration standard, are as follows:

(1) <u>More accurate calibrations.</u> This means that it will be safer to assume that the pavement is rougher than another when the determination is based on Maysmeter measurements made at different times or with different

TABLE 4.1. SERVICEABILITY INDICES FOR THE AUSTIN TEST SECTIONS (SI2)

SEC	JAN 78	APR 78	JUL 78	OCT 78	JAN 79	APR 79
1	3.25	2.12	3.20	3.12	2.92	3.01
2	1.96	2.07	1.55	1.79	2.00	1.25
3	3.77	3.63	3.72	3.66	3.56	3.69
5	3.23	3.19	3.14	4.46	4.41	4.24
6	3.20	3.23	2.60	2.83	2.98	----
7	3.80	4.26	3.77	3.74	4.71	4.50
8	3.34	3.37	3.43	3.33	3.30	3.92
9	3.88	3.69	3.54	3.51	3.52	3.49
10	4.40	4.44	4.43	3.93	4.06	4.49
11	4.21	4.40	4.16	4.25	4.27	4.57
12	3.14	3.13	3.17	2.98	2.17	3.14
13	3.22	3.23	2.77	3.09	3.12	3.11
14	3.63	3.45	3.47	3.49	3.53	3.24
15	3.67	3.75	3.65	3.62	3.56	4.08
19	3.56	3.47	3.35	3.43	3.26	3.44
23	3.51	3.43	3.25	3.07	2.88	3.21
28	3.81	3.67	3.53	3.75	3.64	4.11
32	3.61	3.62	2.53	3.42	3.47	3.68
33	2.61	2.81	2.73	2.45	2.63	2.49
34	3.20	3.35	2.81	2.76	2.65	2.38
35	2.58	2.54	1.77	1.43	1.58	1.96
36	4.36	4.13	4.47	4.06	4.34	4.27
37	3.53	3.37	3.60	2.53	2.60	3.05
38	3.39	3.26	3.00	2.68	2.86	3.39
39	1.88	1.73	1.51	-.80	-.46	----
40	3.70	3.64	----	3.56	3.65	3.78
41	2.63	2.57	2.63	2.30	2.38	1.97
42	1.02	.96	.59	.79	.61	.05
43	1.77	2.04	1.65	2.14	1.92	1.49
44	2.40	2.25	2.62	2.15	2.21	2.00
45	.03	.39	-.06	.61	.10	-.65
SE:	.128	.183	.173	.121	.150	.161

SE TOTAL: .154 (181 Degrees of Freedom)

TABLE 4.2. SERVICEABILITY INDICES FOR THE AUSTIN TEST SECTIONS (SIV)

SEC	JAN 78	APR 78	JUL 78	OCT 78	JAN 79	APR 79
1	3.37	3.23	3.09	3.17	3.15	3.02
2	1.84	1.86	1.62	1.61	1.67	1.33
3	3.67	3.64	3.53	3.75	3.76	3.88
5	3.45	3.38	3.29	4.70	4.66	4.68
6	2.70	2.68	2.31	2.54	2.40	----
7	4.54	4.58	4.24	4.48	4.83	4.81
8	3.78	3.68	3.71	3.69	3.68	3.66
9	3.97	3.97	4.02	3.99	4.01	3.19
10	4.65	4.61	4.67	4.59	4.59	4.50
11	4.34	4.19	4.14	4.11	4.13	4.48
12	3.15	3.09	3.09	2.90	2.11	2.19
13	2.81	2.83	2.72	2.63	2.65	2.47
14	3.86	3.75	3.74	3.73	3.73	3.37
15	3.27	3.41	3.36	3.36	3.38	3.51
19	3.59	3.47	3.48	3.44	3.19	3.75
23	2.97	2.92	2.62	2.69	2.54	2.64
28	4.14	4.09	3.77	4.02	3.98	4.13
32	3.58	3.58	2.91	3.45	3.51	3.51
33	2.78	2.77	2.73	2.47	2.41	1.56
34	2.99	2.98	2.79	2.68	2.68	2.33
35	1.45	1.53	1.75	1.62	1.59	1.23
36	4.15	4.24	4.41	4.17	4.21	4.31
37	3.23	3.07	2.91	2.71	2.32	2.50
38	2.47	2.53	2.41	2.19	2.20	2.03
39	1.88	1.65	2.01	1.11	1.16	----
40	3.32	3.39	----	3.48	3.56	3.53
41	2.29	2.25	2.31	2.03	2.19	1.93
42	1.07	1.10	.94	.82	.85	.81
43	1.25	1.24	1.15	1.91	1.99	1.70
44	1.40	1.38	1.34	1.21	1.23	1.13
45	1.01	1.02	.87	.67	.67	.41
SE:	.034	.062	.044	.034	.044	.050

SE TOTAL: .045 (177 Degrees of Freedom)

units. This is a benefit of the high correlation between Maysmeters and the profile statistic developed to simulate them.

(2) Simplicity. The calibration curves are much easier to deal with if they are linear. In this case the unit's calibration parameters, α_i and β_i , are the easily comprehended slope and intercept. Furthermore, the linear calibration model is by far the most widely used and studied; techniques for obtaining confidence intervals for parameters and estimates, etc., are well established.

(3) Adaptability to future requirements and conditions. The quality of SIV as an estimate of PSR (the mean of a subjective panel rating) might be expected to be less than that of SI2 because of the elimination of components not measurable by the Maysmeter; however, there are reasons to believe that the Maysmeter-derived SIV is not significantly worse than SI2 in predicting PSR and certainly much better for comparing the roughness of roads. Because the SI prediction equation (4.3) is just a rescaling of the calibrated unit's adjusted output, MO, and is free of the calibration process itself (i.e., parameters α_i and β_i), it is easily replaced when better PSR data are obtained. Important to the development of new and better relationships is the preservation of information provided by accurately calibrated Maysmeters.

CONCLUDING REMARKS

It is important not to confuse the problem of calibrating a group of instruments with the problem of interpreting their measurements. When the Texas Maysmeter calibration method was first devised, the Serviceability Index (SI) was the best available estimate of Present Serviceability Rating

Serviceability Rating (PSR), a measure of roughness which is meaningful. Since serviceability estimates were wanted from the Maysmeters, SI was chosen as the standard against which all units were to be calibrated. This would have been a good approach, however, only if Maysmeters were capable of measuring SI with as much accuracy as their precision would seem to indicate. Unfortunately, this is not the case. At best, Maysmeters can be assigned scalings so that different units give comparable "Maysmeter roughness" ratings. How the ratings should be used to predict other things, such as ride quality, is a problem to be considered apart from the calibration process itself.

To help clarify this point with an analogy, suppose that the readings of several homemade thermometers inserted in lakes of a given region correlated fairly well with the number of fish caught during the day. It would be desirable to know that one lake is a better fishing prospect than another, even though they were measured with different thermometers. A decidedly inferior approach to calibrating the thermometers would be to derive for each one of them, separately, a prediction equation by comparing its readings to the number of fish actually caught in a representative sample of lakes. Since the number of fish caught is only partially dependent on lake temperature we must expect that the individual equations derived from such a calibration procedure would be highly variable, depending on our sample lakes, the time of year, etc. Obviously, a much better approach would be to use a standard thermometer to correlate each homemade device with temperature, i.e., with something it is capable of measuring precisely. Then, with the benefit of results from all of the calibrated instruments, one could seek a relationship between temperature and number of fish caught, number of fishermen, or whatever.

The analogy between Maysmeters and thermometers is not perfect, for it is not at all obvious what the equivalent of temperature in pavements should be. Our study of the Texas Maysmeters suggests, however, that a simple profile statistic based on RMSVA can serve effectively as a calibration standard. When the statistic is rescaled by regression techniques to approximate a serviceability rating, we find that different Maysmeters that are calibrated against it can measure roads and agree to within one or two tenths of a serviceability unit. This precision, of course, says nothing about the accuracy of such measurements as predictors of subjective serviceability ratings since the Maysmeter, like the thermometer, is necessarily limited in its response. However, quite apart from providing imperfect estimates of serviceability, it is evident that the Maysmeter is capable of measuring a certain kind of roughness with good precision. The obvious benefit of this is in making comparisons—for example, revealing differences in separate pavements and showing trends in deterioration or the effects of rehabilitation on roughness. It is for this purpose, especially, that a good calibration method based on a stable and valid reference is necessary.

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APPENDIX A

SUMMARY OF AVAILABLE PROGRAMS FOR ROAD PROFILE ANALYSIS

PROGRAMS FOR PROFILE ANALYSIS

CONTENTS

Format for Digital Profilometer Tapes

ONESTEP

SI2

POWER

ROKYRD

DYMOL

QSIM

VERTAC

PLTPROF

Summary Table

PROGRAMS FOR PROFILE ANALYSIS

FORMAT FOR DIGITAL PROFILOMETER TAPES

Each of the computer programs described below accepts as input a magnetic tape which is already two stages of processing removed from the 4-track analog tape produced on board the profilometer. The analog data first undergo A-D processing on an HP2115 system. The resulting 9-track digital tape is then converted to a 7-track format which is compatible with The University of Texas CDC 6600 facility.

The 7-track tape is partitioned into two sets of files. Each file in the first set contains the data for one profilometer run on a section of interest, while files in the second set represent calibration runs in which voltages corresponding to a one-inch step in elevation were imposed. The program, ONESTEP, will accept a one-inch step file and compute the scale factors necessary to transform the data for one or more runs on a section to inches.

A data file consists of a leading two-word IDENT record, the two 60-bit words being used to store the file number, the number of records in the file, the road section number, and the run number. There follows a sequence of 300-word records containing the unscaled profile elevations packed as 12-bit (2's complement) binary integers. The digitization rate normally used (350 Hz) provides 5.92 data points for each foot of road length, with the right and left wheelpath data alternating. Hence, each tape record consists of 300 x 60 ÷ 12 ÷ 2 = 750 pairs of points representing 750 ÷ 5.92 = 126.7 feet of profile.

The programs SI2, ROKYRD, VERTAC, QSIM, and PREDYML each have essentially the same file positioning and data unpacking routines, which can, if necessary, be replaced. The basic requirement of these programs is an array of alternating wheelpath data points and the scale factors necessary to convert these values to inches.

The above procedures for pre-processing profile data are to be revised when the Digital Profilometer replaces the original profilometer hardware because the tape formats, sampling rates, etc. will be different. Minor revisions of the analysis programs will also be required.

ONESTEP

This program accepts the one-inch step files on a digital profilometer tape and computes the right and left wheelpath scale factors. During processing by the other programs, each point (integer) on a data file is converted to inches of elevation by dividing by the appropriate scale factor (typically, a number between 100 and 1000). Hence, the conversion to actual elevations is delayed until the very last stage of processing (Ref 1).

SI2

Used routinely since 1974 to obtain serviceability estimates from a road profile, this program employs the Fast Fourier Transform (FFT) algorithm to extract a set of power spectral averages. Regression on these averages (based on a 1968 panel rating of 86 Texas roads) yields a serviceability estimate (SI) for each file (run) processed. The user specifies the scale factors (obtained from ONESTEP), the file number, and whether the pavement is rigid or flexible. The program simply outputs this information along with the single statistic, SI.

The regression equation incorporated in SI2 is based on a model whose independent variables are mean wavelength amplitudes from 64 discrete wavelength bands. There are 22 terms in the equation, including a constant and a dummy variable (flexible or rigid). The variables correspond to wavelengths ranging from 8.6 feet to 86 feet. The smaller wavelengths were excluded, not because they were poorly correlated with PSR but because of excessive tape recorder noise on the analog tapes from the rated sections. The model, however, was sufficient to explain 89 percent of the variation in panel ratings with a standard error of residuals of .33.

A limitation of SI2 is its lack of generality. It requires elevation data at 1/5.92 = 0.169-ft. intervals expressed as 6.750 right-left wheelpath sample pairs records to define one section 1,140 feet long. The program is not configured so that it can be easily revised without changing to some extent the nature of its serviceability estimate. The measured data points are first reduced in number by 75 percent through application of a linear group-smoothing technique. After removing trends that can distort the low frequency spectral estimates, a "cosine taper-window" is used to correct for end effects—a process that effectively gives less weight to profile characteristics in the first and final 114 feet of the section length. As the spectral values produced by the FFT algorithm are themselves statistical estimates, it was considered appropriate to base them on a fixed quantity of data (Ref 2).

POWER (VERSION 6.0)

Used primarily as a research tool, this program had an important role in the development of the spectral analysis methods for evaluating pavement roughness. POWER utilizes the FFT algorithm to compute a set of power spectral estimates for a specified number of bands. If this number is 64, then a routine is called to compute the same serviceability estimate that the more recent program, SI2, provides. The user may also request printer plots of such statistics as slope variance, coherence, power, and log power.

The computational techniques include low pass filtering to avoid any distortion by subsampling, detrending (subtracting from each series its least squares regression line), and windowing to reduce the effects of finite sample size on the Fourier Transform. These methods are described in references 4 and 5.

Unlike program SI2, POWER permits its user to specify both a decimation rate and the number of points to be used in the computations. Thus, a section of desired length may be analyzed provided the corresponding number of points (after decimation) in each wheelpath is at least four times the number of frequency bands and not more than 2048.

The program provides a summary table listing the band frequencies (cycles per foot), power spectral estimates for right and left profiles (P1 and P2), and the cross-power estimates along with their coherence and phase. A more detailed description of this output can be found in Appendix 1 of reference 4.

ROKYRD (VERSION 2.3)

This program employs digital filtering techniques to obtain a collection of statistics to characterize the measured road profile. The statistics are then used to derive serviceability estimates corresponding to different types of roughness, with separate relationships assumed for flexible and rigid pavements.

The computational method consists of three parts. First, the differences between the outputs of successive low-pass filters are used to isolate irregularities in contiguous passbands. The user can specify the band limits; however, the serviceability equations require data for wavelengths of 4 to 10 feet, 10 to 25 feet, 25 to 50 feet, and 50 to 100 feet. Next, for each passband, a moving root-mean-square amplitude is computed at each point in the corresponding artificial (filtered) profile. Values corresponding to the first and final portions of the section--usually, a distance equal to the longest specified wavelength--are excluded because of distortion by end effects. The final step is to compute the sample frequency distribution of these mean amplitudes.

ROKYRD provides a summary table which lists the mean, standard deviation, and percentiles 50, 75, 90, 95, and 99 for the amplitudes (in inches) for each of the requested passbands. This is done for each wheelpath and for the difference profile: right wheelpath minus left wheelpath. Also, the user of the program may request Calcomp plots of the profile trace of either wheelpath (or of the difference). Both filtered and unfiltered profiles can be plotted, either separately or in the same frame.

Although the serviceability equations built into ROKYRD are derived from essentially the same data (i.e., the 1968 Texas panel rating), they differ in several important respects from the one in program SI2:

(1) Instead of power spectral means, the 50th and 90th percentile values of filtered profile amplitudes are used as independent variables. Thus, the model can in principle distinguish between roads whose roughness is either highly localized or relatively uniform.

(2) Separate models are incorporated to handle the two types of roads: flexible and rigid. The equation for flexible pavements contains eight terms and was sufficient to explain 83 percent ($R^2 = .83$) of the mean rating variability with a residual standard error (SE) of .38. Similar results were obtained for the rigid pavement model ($R^2 = .83$, SE = .32), which contains only six terms, including a dummy variable intended to explain the "auditory or visual differences" between JRCP and CRCP.

(3) Development of these models, like that of SI2, was hindered by the lack of good data in the higher frequency range; however, in this case, an initial filtering operation was believed to have been at least partially successful in eliminating distortion in the 4 to 10-ft wavelength area. Thus, the terms in the ROKYRD equations encompass a slightly broader range of profile wavelengths.

In addition to the overall serviceability estimate, combined, transverse, and longitudinal SI values for each of the four passbands are included in the summary table. Of interest is the fact that the models based solely on wavelengths of 4 to 10 ft fit the original data almost as well as the complete models: $R^2 = .74$ and SE = .45 for flexible pavements and $R^2 = .74$ and SE = .37 for rigid pavements.

ROKYRD is a general program in that it allows the user to specify the step size of digitized data (usually .169 ft), the rate at which these data are to be subsampled, and the wavelength limits of up to 10 passbands to be analyzed. Unlike SI2, a road section of arbitrary length is acceptable provided it is at least more than twice that of the longest profile wavelength of interest (Ref 6).

DYMOL

DYMOL is a generalized mathematical model which characterizes the dynamic behavior of five different classes of highway vehicles. The model consists of a series of interconnected masses, springs, and dashpots and is used to predict the magnitude, duration, and location of dynamic wheel loads applied normally to the roadway surface by the wheels of single unit and articulated vehicles operating under various conditions. The model may be forced upon a natural road profile which is recorded in the field by a profilometer and converted to a suitable digital format.

The sets of differential equations used to describe the motion and calculate the forces between the tire and the road surface are solved by a numerical technique that is based on the assumption that the displacement, the velocities, and the accelerations of the system are known at any particular time. The time increment h may be taken as approximately 1/5 to 1/6 of the shortest period of oscillation, t , to assure convergence and stability of the solution. For the purpose of solving the sets of equations, the value for the wheel to travel a distance of one inch or 0.001 second, whichever is greater, is normally used. This criterion keeps the h-value within the range for convergence and stability. The model is limited to speeds between 10 and 60 mph (176 to 1056 ips).

A tire envelope of 8 inches is estimated by taking a moving average of 46 points (steps) at 0.176 inch, with the average value of these points representing the center of the envelope. DYMOL calculates this as the profile input to the differential equations of motion. The enveloping process allows the model to more accurately represent the tire action of absorbing the effects of small bumps or depressions without displacing the axle.

The program could be modified to accept profile data at larger step sizes. However, to get a reasonable moving average for the tire envelope, at least five points should be used, which implies a maximum step size of two inches.

A separate program, PREDYML, functions as a preprocessor for DYMOL. It accepts a digitized (4000 Hz for 0.176-inch step) profilometer tape along with calibration factors from ONESTEP, unpacks the data, scales the data, and writes onto a new tape only the portion of profile the DYMOL is to be run on in its unpacked and scaled form.

The output of DYMOL consists of printed tables and/or Calcomp plots of the dynamic wheel forces corresponding to distance down the roadway. The printed tables also show the excitations to the tires which are derived from the smoothed profile data. The plots, which are provided only for the left wheel, can portray either the dynamic wheel forces or the axle displacements (Ref 7).

QSIM (VERSION 1.0)

This program is basically a digital version of the Quarter Car Simulator, an electronic device developed by K. J. Law, Inc., to extract from the road profile a roughness measure of a specific type. The Quarter Car Index (QI) was designed to replicate, by means of a mathematical model consisting of a tire-wheel mass, suspension spring, shock absorber, and vehicle mass, the Roughness Index (RI) of the Bureau of Public Roads Roughometer.

In QSIM, the differential equations describing the motion of the model components (i.e., the sprung and unsprung masses) are solved by digital, rather than analog, methods. More specifically, the transition matrix method is applied to the series of profile elevations from a digitized profilometer tape. The relative motion, in the upward direction, between the wheel axle and the sprung frame is integrated for a fixed distance along the road. The result is QI, which has units of inches per mile.

In addition to the tape input, the user of QSIM provides information such as step-size of digitized data, scale factors, section identification method, and speed at which the quarter-car is to be simulated. A preliminary comparison between the electronic (analog) and digital versions of QI on several Brazilian roads showed very good agreement between the methods (Refs 8 and 9).

VERTAC

Developed as part of research done in early 1978 to derive a Maysmeter calibration standard, VERTAC provides a set of roughness statistics closely related to the physical concept of vertical acceleration. The basic algorithm, which is numerically much simpler than either spectral analysis or digital filtering, can be stated here.

Let Y_1 , Y_2 , . . ., Y_n be elevations in inches or equally spaced points along one wheelpath of the profile and let b be the distance between adjacent points. Then a simple estimate of the second derivation of Y at point i is

$$(S_b)_i = (Y_{i+1} - 2Y_i + Y_{i-1})/b^2$$

Hence, the root-mean-square vertical acceleration (RMSVA) at base length b is defined as

$$VA_b = C \left(\sum_{i=2}^{N-1} (S_b)_i^2 / (N - 2) \right)^{\frac{1}{2}}$$

where C is the constant that transforms units to ft/sec for a given vehicle speed. By default, a 50 mph speed is assumed.

An examination of profilometer data will reveal that the index VA increases sharply as b decreases, but that VA is selectively sensitive to roughness amplitudes of wavelengths 2b. VERTAC lists the RMSVA indices at base lengths b = .5, 1, 2, 4, 8, 16, 32, and 65 feet for each wheelpath.

Also provided is a Maysmeter roughness estimate in counts/.2 mile:

$$\text{Mo} = -20 + 23\text{VA}_4 + 58\text{VA}_{16} \quad ,$$

and a serviceability estimate based on Maysmeter roughness:

$$\text{SIV} = 5 \exp \left[- \left(\frac{ln(32\ \text{MO})}{8.49331} \right)^{9.35661} \right]$$

The index Mo was adequate to describe quite well the response of eight Texas Maysmeters on 29 road sections near Austin. The measurement of a particular Maysmeter, for example, is predicted by $M_k = A_k + B_k \text{Mo}$, where A_k and B_k are calibration constants close to 0 and 1 (trailer units) or to 10 and 1.5 (car units). For a typical Maysmeter trailer, the standard error of prediction is less than 10 counts/.2 mile while the mean roughness of the Austin test sections is about 100 counts/.2 mile.

The index SIV was obtained by calibrating the simulated Maysmeter Mo against the serviceability index computed by program SI2--the same technique used in the past for calibrating the Texas Maysmeters. In effect, the RMSVA index is scaled to a number between 0 and 5.

In order to identify spurious data on the tape, VERTAC writes on a separate output file the maximum elevations between adjacent points on each data record and identifies all points with such differences greater than one inch. This was found to be necessary because of occasional faults in the digitization process.

PLTPROF

PLTPROF is a program that takes a digitized profilometer tape and plots the profile on a Calcomp plotter using ONESTEP calibration factors and an input step size corresponding to the digitization rate. It can plot any portion of the profile specified on any X and Y scale within limits of the plotter (.005 in. is the smallest increment).

SUMMARY OF ROAD PROFILE ANALYSIS PROGRAMS

Name	Description	User Input	Profile Input	Output	Lines of Code
ONESTEP	Computes wheel path scale factors from one-inch step files	First file no., no. of files to process	Tape	List	178
SI2	Computes present serviceability estimate from spectral estimates	Section ID, scale factors, file no., pavement type	Tape	List	536
POWER 6	Performs power spectral analysis of road profile	No. points, scale factors, no. bands, decimation rate, plot options	Tape	Tables/ printer plots	722
ROKYRD	Provides amplitude statistics and serviceability estimates from filtered profiles	File no., section limits, step size, decimation rate, band options, plot options, pavement type	Tape or cards	Tables/ plots	1007
DYMOL	Models the dynamic wheel forces of five classes of trucks	Truck class, speed, plot/ print options	Tape from PREDYML	Tables/ plots	3084
PREDYML	Writes an unpacked and scales data tape for DYMOL	File no., scale factors, step size, section limits	Tape	Tape for DYMOL	82
QSIM	Computes a Quarter Car Index from road profile	Section ID, scale factors, step size, file no., speed of simulated vehicle	Tape or cards	List	410
VERTAC	Computes vertical acceleration (RMSA) indices and simulates Mays Meter roughness	Section ID, scale factors, step size, file no., speed of simulated vehicle	Tape or cards	Tables	
PLTPROF	Provides Calcomp plots of unfiltered profile	File no., axes lengths, step size, section limits, wheelpath, scale factor	Tape	Plots	342

APPENDIX B

VERTAC--USER'S GUIDE
AND SOURCE LISTING

VERTAC--USER'S GUIDE AND SOURCE LISTING

DESCRIPTION OF ITEMS ON THE VERTAC PRINTOUT

1. Title (usually a road name), date of profilometer run, section number, and run number.

2. Length of section actually processed (in feet), along with profilometer tape format and positioning information.

3. GAINR, GAINL - right wheelpath and left wheelpath scale factors used by program to convert profile elevations to proper units.

4. A row of roughness indices corresponding to each RMSVA baselength examined - normally, multiples of the sampling interval (.169 ft) in the range .5 ft to 130 ft:

Col 1	base length (feet)
Col 2	right wheelpath RMSVA
Col 3	left wheelpath RMSVA
Col 4	mean RMSVA from both wheelpaths
Col 5	SI value - Eq 2 with MO replaced with a linear function the mean RMSVA (col 4)

5. MRM Roughness (counts/.2 mile) - equivalent to MO (Eq 1) with units inches/mile.

6. Flexible Pavement Serviceability - SIV (Eq 2).

```
      PROGRAM VERTAC(INPUT=65,DATA=513,OUTSAV=65,OUTPUT=65,
     .     TAPE1,TAPE2=DATA,TAPE4=OUTSAV,TAPE5=INPUT,TAPE6=OUTPUT)
C
C***********************************************************************
C
C
C                            -- VERTAC --
C
C                      VERSION 2.2 - MARCH 1981
C
C                      LAST UPDATED: 21 APR 81
C
C
C      THIS PROGRAM COMPUTES THE ROAD PROFILE STATISTIC ROOT-MEAN-
C      SQUARE VERTICAL ACCELERATION (RMSVA) AT A SEQUENCE OF USER-
C      SPECIFIED BASE LENGTHS (MULTIPLES OF DATA SAMPLING INTERVAL).
C      THE MAYS METER SIMULATION M0 (MRM) IS COMPUTED PROVIDED THE
C      COMPONENT RMSVA INDICES (FOR BASE LENGTHS 4 FEET AND 16 FEET)
C      ARE ALSO COMPUTED.  IN ADDITION, THE SERVICEABILITY INDEX
C      SIV, WHICH IS A FUNCTION OF M0, IS OUTPUT FOR EACH MEASURED
C      ROAD SECTION.  DATA SMOOTHING AND SUBSAMPLING OPTIONS ARE
C      PROVIDED FOR THE USER.
C
C
C                             WRITTEN BY
C
C                            DAVID MCKENZIE
C                           PRENTISS RIDDLE
C
C                  CENTER FOR TRANSPORTATION RESEARCH
C                  THE UNIVERSITY OF TEXAS AT AUSTIN
C                         AUSTIN, TEXAS 78712
C
C***********************************************************************
C
C                      --  INPUT FORMAT  --
C
C  NOTE: CARDS 1 AND 2 FORM A PAIR WHICH MAY BE REPEATED FOR AS MANY
C        RUNS AS DESIRED.
C
C
C                   CARD 0 -- FORMAT(A6)
C
C   IDATE     DATE
C
C                   CARD 1 -- FORMAT(8A10)
C
C   TI        RUN INFORMATION
C
C                   CARD 2 -- FORMAT(4I5,4F10.0,2F5.0,2A1)
C
C   IFILE     NO. OF FILE ON TAPE1.  IF LE 0, IFILE WILL BE SET EQUAL TO
C             ONE.  FILE NOS. FOR SUCCESSIVE SECTIONS MUST BE IN
C             ASCENDING ORDER.
C   NREC      NO. OF FIRST RECORD ON FILE TO BE READ.  IF NREC LT 0,
```

```
C              DATA WILL BE READ FROM FILE *DATA* INSTEAD OF TAPE1.
C              NREC DEFAULTS TO 1.  FORMAT(10I5).
C   IDEC       SAMPLING RATE.  IDEC-1 POINTS ARE DISCARDED (AFTER
C              SMOOTHING) FOR EACH POINT ACCEPTED. DEFAULT IS 1.
C   ISM        SMOOTHING INDEX.  EACH POINT WILL BE REPLACED BY THE
C              WEIGHTED AVERAGE OF 2*ISM+1 ADJACENT POINTS.
C              DEFAULT IS 0.
C   GAINR,     FACTORS TO CONVERT PROFILE ELEVATIONS TO INCHES.
C   GAINL      POSITIVE VALUES ARE ALWAYS REQUIRED.
C   DIST       LENGTH OF SECTION OF INTEREST (FEET).  DEFAULT IS 1050 FT.
C   SKP        DISTANCE OF SECTION FROM START OF FIRST RECORD.
C              SKP DEFAULTS TO 0 FT.
C   STEPIN     STEP SIZE OF ORIGINAL DATA ON TAPE1. DEFAULTS TO .169 FT.
C   BASE1      THE FIRST BASE LENGTH FOR WHICH RMSVA IS TO BE COMPUTED
C              IS THE LARGEST MULTIPLE OF IDEC*STEPIN WHICH IS LESS THAN
C              OR EQUAL TO BASE1.  IT WILL BE DOUBLED 9 TIMES TO OBTAIN A
C              TOTAL OF 10 INDICES.  DEFAULT IS .5 FT.
C   NWR        IF NWR IS *W*, UNSCALED DECIMATED DATA FROM TAPE1 WILL BE
C              WRITTEN ONTO FILE *DATA*.  FORMAT(10I5).
C              IF NWR IS *S*, SCALED DECIMATED DATA WILL BE WRITTEN TO
C              FILE *DATA* IN FORMAT (3F10.4) --
C              DISTANCE, RIGHT WHEELPATH VALUE, LEFT WHEELPATH VALUE.
C   NCHK       THE LETTER *N* IN COL.72 WILL SUPPRESS ERROR CHECKING AND
C              RESIDUAL STATISTICS DURING SMOOTHING.
C
C          NOTE:  TO OBTAIN AN MRM SIMULATION AND A SERVICEABILITY
C                 ESTIMATE, INDICES FOR BASE LENGTHS NEAR 4FT AND 16FT
C                 MUST BE COMPUTED (SEE BASE1).
C
C************************************************************************
C
C  A NOTE ON ■OUTSAVE■ FILES --
C
C       THE PROGRAM ■VERTAC■ PRODUCES, IN ADDITION TO ITS ORDINARY OUT-
C  PUT, A FILE CONTAINING A SUMMARY OF ITS NUMERICAL RESULTS.  THIS
C  FILE, CALLED THE ■OUTSAVE■ FILE, IS USED BY OTHER PROGRAMS WHICH
C  PRINT THESE RESULTS IN TABULAR FORM.  MOST NOTABLE OF THESE PRO-
C  GRAMS IS ■SIAUS■, WHICH SUMMARIZES SIV VALUES FOR AUSTIN TEST
C  SECTIONS PRODUCED BY A NUMBER OF RUNS OF ■VERTAC■.
C
C       THE FORMAT OF AN ■OUTSAVE■ FILE IS AS FOLLOWS:
C  FIRST CARD -- THE DATE IN (A6) FORMAT.
C  ADDITIONAL CARDS -- THE FOLLOWING IN (I3,4F7.2,2F7.3,5F7.4) FORMAT:
C     NSEC      SECTION NUMBER
C     RM0       MRM ROUGHNESS (COUNTS/.2 MILE)
C     SIV       PAVEMENT SERVICEABILITY
C     RM(3,1)   RMS VERT. ACCEL. (FT/SEC**2) AT 50 MPH, BASE LENGTH = .5
C     RM(3,2)    "    "     "       "        "      "     "     = 1
C     RM(3,3)    "    "     "       "        "      "     "     = 2
C     RM(3,4)    "    "     "       "        "      "     "     = 4
C     RM(3,5)    "    "     "       "        "      "     "     = 8
C     RM(3,6)    "    "     "       "        "      "     "     = 16
C     RM(3,7)    "    "     "       "        "      "     "     = 32
C     RM(3,8)    "    "     "       "        "      "     "     = 65
C     RM(3,9)   RMS VERT. ACCEL. (FT/SEC**2) AT 50 MPH, BASE LENGTH = 130
C
C       WHENEVER ■VERTAC■ IS RUN ON AUSTIN TEST DATA, THE RESULTING
C  ■OUTSAVE■ FILE SHOULD BE STORED AS THE FIRST RECORD OF A MULTI-
C  RECORD FILE OF COLLECTED VERTAC RESULTS.  (THE MACRO ■PACKOS■ WAS
C  WRITTEN TO DO THIS.)  ONCE THIS IS DONE, THE MULTI-RECORD ■OUTSAVE■
C  FILE PRODUCED IS READY TO BE USED AS INPUT TO ■SIAUS■.
C
```

```
C**********************************************************************
C
      COMMON /SMTH/ ISM,C(21),SUMC(2),IDEC,IC,NXOB,NXDA,NPR
      COMMON /PACK/ ID(5),IN(300)
      COMMON /STAT/ NOCHK,RESS,RMAX,MAXR,OBSR(21),LIMR,SCL(2)
      COMMON // DAT(2,7000),OBS(1500)
C
      DIMENSION IO(1500), TI(8), V(2), RM(3,9), STEP(9), IODAT(2,1)
      DIMENSION BL(9), A0(9), A1(9), SIVA(9)
      EQUIVALENCE (IO,OBS), (DAT,IODAT)
      LOGICAL NOCHK
C
      DATA NEQ/9/
      DATA BL /0.5, 1.0, 2.0, 4.0, 8.0, 16.0, 32.0, 64.0, 128.0/
      DATA A0 /52.715, 16.162, -28.588, -23.506, 6.125, 10.831, 10.103,
     .         19.275, 26.303/
      DATA A1 /0.56721, 2.9354, 13.383, 34.464, 66.132, 139.18, 296.66,
     .         602.00, 1643.8/
      DATA LREC/0/,MAXN/7000/,MAXSTP/9/,SPEED/50./,MXISM/10/
      DATA B0,B1,B2/-20.,.23,.58/,DLIM/1.0/
C
      REWIND 2
      REWIND 4
      READ (5,10) IDATE
      WRITE (4,10) IDATE
   10 FORMAT (A6)
C
C     READ TITLE CARD AND DATA CHARACTERISTICS
C
      NPG = 1
      NRN = 0
   20 READ 30, TI
   30 FORMAT (8A10)
      IF (EOF,5) 40,50
   40 CALL EXIT
   50 READ 60, IFILE,NREC,IDEC,ISM,SCL,DIST,SKP,STEPIN,BASE1,NWR,NCHK
   60 FORMAT (4I5,4F10.0,2F5.0,2A1)
      IF (NRN.EQ.0)  PRINT 70, NPG
   70 FORMAT (1H1/1H0,6X,31HPROGRAM VERTAC - VERSION 2.1 - ,
     .          16HREVISED 04/21/81,12X,4HPAGE,I3//1H0,6X,66(1H*))
      PRINT 80, TI
   80 FORMAT (1H0,6X,8A10)
      IF (IFILE.LE.0) IFILE = 1
      IF (BASE1.LE.0.) BASE1 = .55
      IF (STEPIN.LE.0.) STEPIN = 0.169
      IF (DIST.LE.0.) DIST = 1050.
      IF (IDEC.LE.0) IDEC = 1
      IF (NREC.EQ.0) NREC = 1
      INF = 1
      IF (NREC.LT.0) INF = IFILE = 2
      NOCHK = .F.
      IF (NCHK.EQ.1HN .OR. ISM.EQ.0) NOCHK = .T.
C
C     INITIALIZE FOR NEW SECTION
C
      NRN = NRN+1
      MDIST = DIST+.5
      NSKP = SKP/STEPIN
      MSKP = NSKP*STEPIN+.5
      PRINT 90,  MDIST,MSKP,NREC,IFILE
   90 FORMAT (/6X,I5, 18H FT SECTION BEGINS,I4, 21H FT FROM START OF REC
     .,I3,  8H OF FILE,I3)
```

```
      NP = DIST/STEPIN
      N = NP+NSKP
      N2 = N+N
      NS = NSKP+NSKP
      MX = (NP-2*ISM)/IDEC
      IF (MX.GT.MAXN)  GO TO 470
C
C     UNPACK DATA FROM TAPE1 OR FILE <DATA>
C
      IF (INF.EQ.1) CALL POSITP (IFILE,NREC,LREC,NSEC)
      NWORDS = 300
      NXDA = 1
      CALL INITSM (ISM,C)
      NXOB = NSKP+ISM+1
      RMAX = 0.
      SUMC(2) = RMAX
      SUMC(1) = SUMC(2)
      RESS = SUMC(1)
      IC = 0
      NRPTS = N2
  100 NPR = MIN0(750,NRPTS/2)
      L = 2*NPR
      IF (INF.EQ.1) READ (1) IN
      IF (INF.EQ.2) READ (2,110) (IO(K),K=1,L)
  110 FORMAT (14I5)
      IF (EOF,INF) 120,140
  120 PRINT 130,  N,IFILE
  130 FORMAT (6X, 47HEND OF FILE ENCOUNTERED WHEN ATTEMPTING TO READ,I5,
     . 26H PAIRS OF POINTS FROM FILE,I3)
      STOP 3
  140 IF (INF.EQ.2)  GO TO 150
      LREC = LREC+1
      IF (NRPTS.LT.1500) NWORDS = (NRPTS+4)/5
      NXTIO = 1
      CALL UNPACK (NWORDS,NXTIO,IO)
  150 DO 160 I=1,L
  160 OBS(I) = IO(I)
      CALL SMOOTH (OBS,DAT)
      NRPTS = NRPTS-1500
      IF (NRPTS.GT.0)  GO TO 100
C
      N = NXDA-1
      N2 = 2*N
      RESE = 0.
      IF (.NOT.NOCHK) RESE = SQRT(RESS*2/N2)
      IF (NWR.NE.1HW)  GO TO 190
C
C     PLACE UNSCALED DATA ON TAPE2 = DATA.
C
      REWIND 2
      DO 170 K=1,N
      DO 170 I=1,2
  170 IODAT(I,K) = DAT(I,K)+.5
      WRITE (2,110) ((IODAT(I,K),I=1,2),K=1,N)
      DO 180 K=1,N
      DO 180 I=1,2
  180 DAT(I,K) = IODAT(I,K)
C
C     SCALE TO INCHES AND COMPUTE VERTICAL ACCELERATION.
C
  190 STEPIN = IDEC*STEPIN
      IF (ISM .NE. 0)  PRINT 200,  STEPIN,ISM,RESE
```

```
  200 FORMAT (6X, 19H SAMPLING INTERVAL=,F5.2,5X,  4HISM=,I2,5X,  3HSF=,
     .F6.4)
      PRINT 210,  SCL
  210 FORMAT (1H0,16X,  6HGAINR=,F7.1,12X,  6HGAINL=,F7.1)
      IF (SCL(1).LE.0. .OR. SCL(1).GE.2000.)  GO TO 490
      IF (SCL(2).LE.0. .OR. SCL(2).GE.2000.)  GO TO 490
      DO 220 I=1,N
         DAT(1,I) = DAT(1,I)/SCL(1)
         DAT(2,I) = DAT(2,I)/SCL(2)
  220 CONTINUE
C
C     WRITE OUT MAXIMUM DISPLACEMENTS
C
      K = 1
      DIF1 = 0.
      DO 230 I=2,N
         DIF2 = AMAX1( DIF1, ABS(DAT(1,I)-DAT(1,I-1)),
     .                       ABS(DAT(2,I)-DAT(2,I-1)) )
         IF (DIF2.GT.DIF1) K = I
         DIF1 = DIF2
  230 CONTINUE
      PRINT 240,  DIF1,K*(STEPIN/TDEC)
  240 FORMAT (90X,  6H STEP=,F6.2,  7H IN  AT,F7.1,  4H FT.)
C
      NSTP = MAX1(BASE1/STEPIN,1.)
      NMSTP = 0
C
C     WRITE SCALED DATA IN FORMAT SUITABLE FOR PLOTTING
C
      IF (NWR.NE.1HS)  GO TO 270
      REWIND 2
      TIM = 0.
      DO 250 I=1,N
         WRITE (2,260) TIM,DAT(1,I),DAT(2,I)
  250 TIM = TIM+STEPIN
  260 FORMAT (3F10.4)
C
  270 INC2 = NSTP+NSTP
      NM = N-INC2
      IF (NM.LT.1)  GO TO 290
      NMSTP = NMSTP+1
      V(2) = 0.
      V(1) = V(2)
      DO 280 I=1,2
      DO 280 J=1,NM
  280 V(I) = V(I)+(DAT(I,J)-2.*DAT(I,J+NSTP)+DAT(I,J+INC2))**2
      STEP(NMSTP) = NSTP*STEPIN
      TIM = (12.*STEP(NMSTP)/(17.6*SPEED))**2
      RM(1,NMSTP) = SQRT(V(1)/NM)/(TIM*12.)
      RM(2,NMSTP) = SQRT(V(2)/NM)/(TIM*12.)
      RM(3,NMSTP) = (RM(1,NMSTP)+RM(2,NMSTP))*.5
      IF (NMSTP.GE.MAXSTP)  GO TO 295
      NSTP = 2*NSTP
      GO TO 270
C
  290 MAXSTP = NMSTP
      IF (NMSTP.LE.0)  GO TO 510
  295 CONTINUE
C
C     CALCULATE SI VALUES ASSOCIATED WITH VERTICAL ACCELERATIONS
C
      DO 320 K=1,MAXSTP
```

```
         SIVA(K) = 0.0
C        ** TRY TO MATCH BASE LENGTHS
         DO 300 J=1,NEQ
            IF (PCTERR(BL(J),STEP(K)).LE.10.0)  GO TO 310
  300    CONTINUE
         GO TO 320
  310    CONTINUE
C        ** THERE IS AN EQUATION FOR BASE LENGTH STEP(K)
         SIVA(K) = SIM0 ( A0(J)+A1(J)*RM(3,K) )
  320 CONTINUE
C
C     PRINT RESULTS
C
      PRINT 360
      DO 350 K=1,MAXSTP
         PRINT 370,  STEP(K),(RM(I,K),I=1,3)
         IF (SIVA(K).LE.0.0)  GO TO 340
         PRINT 380,  SIVA(K)
         GO TO 350
  340    PRINT 390
  350 CONTINUE
  360 FORMAT (7X, 48HRMS VERTICAL ACCELERATION (FT/SEC SQ) AT 50 MPH:,/1
     ,H0,6X, 45HBASE LENGTH   RIGHT      LEFT    COMBINED    : 12HESTIMA
     .TED SI,/)
  370 FORMAT (11X,F5.1,3F10.2)
  380 FORMAT (1H+,53X,F6.2)
  390 FORMAT (1H+,55X,4H----)
C
      DO 400 I=1,MAXSTP-2
         IF (STEP(I).GT.3.8 .AND. STEP(I).LT.4.2)  GO TO 410
  400 CONTINUE
      GO TO 450
  410 RM0 = B0+B1*RM(3,I)+B2*RM(3,I+2)
      PRINT 420,  RM0
  420 FORMAT (1H0,6X, 31HMRM ROUGHNESS (COUNTS/.2 MILE):,F12.2)
      IF (RM0.LE.0.)  GO TO 450
      SI2 = SIM0 ( RM0 )
      PRINT 430,  SI2
  430 FORMAT (1H0,6X,33HFLEXIBLE PAVEMENT SERVICEABILITY:,F10.2)
      WRITE (4,440) NSEC,RM0,SI2,(RM(3,K),K=1,MAXSTP)
  440 FORMAT (I3,4F7.2,2F7.3,5F7.4)
  450 PRINT 455
  455 FORMAT (/7X,66(1H*))
      IF (NRN.GE.2)  NRN = 0
      IF (NRN.EQ.0) NPG = NPG+1
      IF (NOCHK)  GO TO 20
      PRINT 460,  MAXR,SQRT(RMAX),RESE,(OBSR(K),K=1,LIMR)
  460 FORMAT (1H+,84X,3HPR:,I5,6H  RES:,F7.3,5H  SE:,F7.4,6H  PTS:,
     .         F6.0,3(/85X,7F6.0))
      GO TO 20
C
C
  470 PRINT 480,  MX,MAXN
  480 FORMAT (6X,  5H ----,I7, 36H POINT PAIRS REQUIRED FOR DISTANCE -,
     , 5H ONLY,I6,  9H ALLOWED.,/13X, 35HDECIMATE DATA OR INCREASE DIMEN
     .SION, 14H OF ARRAY DAT.)
      STOP 1
C
  490 PRINT 500
  500 FORMAT (6X, 29HERROR---INVALID SCALE FACTORS)
      STOP 2
C
```

```
  510 PRINT 520
  520 FORMAT (6X, 46H **** NOT ENOUGH POINTS TO COMPUTE FIRST RMSVA)
      STOP 3
C
      END
```

```
      FUNCTION SIM0 ( RM0 )
C
C     FUNCTION TO CONVERT AN M0 VALUE TO AN SI VALUE.
C
      DATA ALPHA,BETA / 9.35661, 8.49331 /
C
      IF (RM0 .LE. 0.0)  GO TO 100
C
      SIM0 = 5.0*EXP(-(ALOG(32.0*RM0)/BETA)**ALPHA)
      RETURN
C
100   SIM0 = 5.0
      RETURN
C
      END
```

```
      FUNCTION PCTERR ( A , B )
C
C     ROUTINE TO CALCULATE PERCENTAGE ERROR (ABS(A-B) AS A PERCENTAGE
C     OF ABS(B)).
C
      IF (B .EQ. 0.0)  GO TO 100
C
      PCTERR = ABS( (A-B)/B ) * 100.0
      RETURN
C
100   PCTERR = ABS(A)
      RETURN
      END
```

```
      SUBROUTINE INITSM(ISM,C)
C
C  COMPUTES SMOOTHING COEFFICIENTS FOR OBSERVATIONS OF
C  POLYNOMIAL TRENDS OF DEGREE THREE.
C
      DIMENSION C(21)
C
      C(1)=1.
      IF(ISM.LE.0) RETURN
      IF(ISM.GT.1) GO TO 20
      DO 10 I=1,3
```

```
10      C(I)=1./3.
        RETURN
C
20      K1=9*(ISM*ISM+ISM)-3
        S2=(2*ISM-1)*(2*ISM+1)*(2*ISM+3)
        DO 30 I=0,ISM
30      C(ISM+1-I)=C(ISM+1+I)=(K1-15*I*I)/S2
        RETURN
        END
```

```
        SUBROUTINE SMOOTH(OBS,DAT)
        COMMON /SMTH/ISM,C(21),SUMC(2),IDEC,IC,NXOB,NXDA,NPR
        COMMON /STAT/ NOCHK,RESS,RMAX,MAXR,OBSR(21),LIMR,SCL(2)
        DIMENSION OBS(2,1),DAT(2,1),OBSL(2)
        LOGICAL NOCHK
        DATA OBSL/0.,0./
C
        MAXC=ISM+ISM+1
C
5       M1=MAX0(1,NXOB-ISM)
        IF(M1.GT.NPR) GO TO 30
        M2=MIN0(NXOB+ISM,NPR)
        IF(NOCHK.OR.NXOB.LT.M1.OR.NXOB.GT.M2) GO TO 6
        OBSL(1)=OBS(1,NXOB)
        OBSL(2)=OBS(2,NXOB)
C
6       DO 10 M=M1,M2
        IC=IC+1
        DO 10 I=1,2
10      SUMC(I)=SUMC(I)+OBS(I,M)*C(IC)
C
        IF(IC.LT.MAXC) GO TO 30
        IC=0
        DO 20 I=1,2
        DAT(I,NXDA)=SUMC(I)
        IF(NOCHK) GO TO 20
C
        RES=((OBSL(I)-SUMC(I))/SCL(I))**2
        RESS=RESS+RES
        IF(RES.LE.RMAX) GO TO 20
        RMAX=RES
        MAXR=NXDA
        K=0
        DO 15 M=M1,M2
        K=K+1
15      OBSR(K)=OBS(I,M)
        LIMR=K
C
20      SUMC(I)=0.
C
        NXDA=NXDA+1
        NXOB=NXOB+IDEC
        GO TO 5
C
30      NXOB=NXOB-NPR
        RETURN
        END
```

```
PROGRAM VERTAC - VERSION 2.2 - REVISED 04/21/81            PAGE  1

**********************************************************************

   AUSTIN TEST  ---  APRIL 1981  ---  SEC.  1,  RUN 1

1050 FT SECTION BEGINS   0 FT FROM START OF REC  1 OF FILE  2
(FILE:    2   SEC:  1   RECORDS:     9)

          GAINR:  283.4              GAINL:  278.1

RMS VERTICAL ACCELERATION (FT/SEC SQ) AT 50 MPH:

BASE LENGTH   RIGHT      LEFT    COMBINED    ESTIMATED SI

        .5    78.18     77.29     77.74          2.75
       1.0    26.26     26.19     26.23          2.82
       2.0     8.02      8.01      8.02          3.13
       4.1     2.81      2.63      2.72          3.32
       8.1     1.17       .96      1.06          3.18
      16.2      .56       .52       .54          2.98
      32.4      .33       .30       .31          2.62
      64.9      .15       .14       .14          2.59
     129.8      .06       .04       .05          2.47

MRM ROUGHNESS (COUNTS/.2 MILE):        73.83

FLEXIBLE PAVEMENT SERVICEABILITY:       3.24

**********************************************************************

   AUSTIN TEST  ---  APRIL 1981  ---  SEC.  1,  RUN 2

1050 FT SECTION BEGINS   0 FT FROM START OF REC  1 OF FILE  3
(FILE:    3   SEC:  1   RECORDS:     9)

          GAINR:  283.4              GAINL:  278.1

RMS VERTICAL ACCELERATION (FT/SEC SQ) AT 50 MPH:

BASE LENGTH   RIGHT      LEFT    COMBINED    ESTIMATED SI

        .5    74.04     76.00     75.02          2.78
       1.0    25.36     26.21     25.79          2.85
       2.0     8.12      7.95      8.04          3.13
       4.1     2.89      2.65      2.77          3.28
       8.1     1.27       .96      1.11          3.11
      16.2      .60       .52       .56          2.91
      32.4      .33       .32       .32          2.58
      64.9      .14       .14       .14          2.57
     129.8      .05       .05       .05          2.53

MRM ROUGHNESS (COUNTS/.2 MILE):        76.24

FLEXIBLE PAVEMENT SERVICEABILITY:       3.19

**********************************************************************
```

```
PROGRAM VERTAC - VERSION 2.2 - REVISED 04/21/81            PAGE  2

**************************************************************

   AUSTIN TEST  ---  APRIL 1981  ---  SEC. 2.  RUN 1

1050 FT SECTION BEGINS   0 FT FROM START OF REC  1 OF FILE  4
(FILE:    4   SEC:  2   RECORDS:     9)

          GAINR:  378.2              GAINL:  374.1

RMS VERTICAL ACCELERATION (FT/SEC SQ) AT 50 MPH:

BASE LENGTH    RIGHT       LEFT    COMBINED    ESTIMATED SI

        .5    102.14      86.37     94.25          2.57
       1.0     40.66      30.84     35.75          2.31
       2.0     15.62      10.90     13.26          1.89
       4.1      7.17       4.54      5.86          1.53
       8.1      3.04       1.85      2.45          1.65
      16.2      1.19        .81      1.00          1.87
      32.4       .48        .39       .44          2.03
      64.9       .22        .18       .20          1.99
     129.8       .07        .07       .07          1.94

MRM ROUGHNESS (COUNTS/.2 MILE):       172.74

FLEXIBLE PAVEMENT SERVICEABILITY:       1.59

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   AUSTIN TEST  ---  APRIL 1981  ---  SEC. 2.  RUN 2

1050 FT SECTION BEGINS   0 FT FROM START OF REC  1 OF FILE  5
(FILE:    5   SEC:  2   RECORDS:     9)

          GAINR:  378.2              GAINL:  374.1

RMS VERTICAL ACCELERATION (FT/SEC SQ) AT 50 MPH:

BASE LENGTH    RIGHT       LEFT    COMBINED    ESTIMATED SI

        .5    100.91      85.90     93.40          2.58
       1.0     39.85      29.83     34.84          2.35
       2.0     15.15      10.65     12.90          1.96
       4.1      6.92       4.47      5.69          1.59
       8.1      2.93       1.90      2.41          1.67
      16.2      1.15        .81       .98          1.91
      32.4       .48        .38       .43          2.05
      64.9       .22        .17       .20          2.05
     129.8       .07        .07       .07          2.04

MRM ROUGHNESS (COUNTS/.2 MILE):       167.97

FLEXIBLE PAVEMENT SERVICEABILITY:       1.65

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APPENDIX C

MRMCAL2--USER'S GUIDE AND SOURCE LISTING

```
      PROGRAM MRMCAL3 ( INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C
C          M  R  M  C  A  L  3              UPDATED: 8 MAY 1981
C
C
C*********************************************************************
C
C     MRMCAL3 IS A PROGRAM USED TO CALIBRATE A MAYS ROAD METER AGAINST
C     AN AVAILABLE ROUGHNESS STATISTIC (MO) WITH WHICH IT ASSUMED TO
C     HAVE A LINEAR RELATIONSHIP:
C
C            MPI  =  ALPHA  +  BETA * MO
C
C     WHERE -MPI- IS THE PREDICTED RAW READING (COUNTS PER .2 MILE) OF
C     THE MAYSMETER TO BE CALIBRATED AND -MO- IS THE PROFILE-DERIVED
C     MAYSMETER SIMULATION USED AS THE CALIBRATION STANDARD.
C
C         ONCE THE PARAMETERS -ALPHA- AND -BETA- ARE OBTAINED, THE
C     MAYSMETER RAW READINGS, -MI- (COUNTS PER .2 MILE), CAN BE TRANS-
C     FORMED TO CALIBRATED VALUES BY
C
C            MCI  =  ( MPI - ALPHA )  /  BETA
C
C     WHERE -MCI- IS A MAYSMETER-DERIVED ESTIMATE OF -MO-  (THE *IDEAL
C     MAYSMETER*).
C
C         FINALLY, THE CALIBRATED VALUES (-MCI-) CAN BE TRANSFORMED TO
C     SERVICEABILITY INDICES BY THE RELATION
C
C            SIV  =  5.0 * EXP( -(ALOG(32.0*MCI)/8.49331) ** 9.35661 ) .
C
C
C     FOR MORE INFORMATION SEE CTR REPORT NO. 251-1.
C
C*********************************************************************
C
C     MRMCAL3 WAS WRITTEN IN APRIL 1981 BY PRENTISS RIDDLE AND DAVID
C     MCKENZIE OF THE CENTER FOR TRANSPORTATION RESEARCH AT THE
C     UNIVERSITY OF TEXAS AT AUSTIN.
C
C*********************************************************************
C*********************************************************************
C
C
C    INPUT GUIDE --
C
C
C    AN INPUT DATA FILE CONSISTS OF ONE IDENTIFICATION CARD FOLLOWED BY
C       DATA FOR UP TO 35 SECTIONS.
C
C    THE DATA FOR A SECTION CONSIST OF ONE SECTION HEADER CARD FOLLOWED
C       UP TO TEN RUN CARDS.
C
C    THE FORMATS FOR THE VARIOUS SORTS OF CARD-IMAGES ARE AS FOLLOWS:
```

```
C                                                                       MR  560
C                                                                       MR  570
C    IDENTIFICATION CARD -   FORMAT (A16,X,A4,X,I2,X,A16,X,A8,X,I2,     MR  580
C                                    X,A1,X,A1)                         MR  590
C                                                                       MR  600
C      COLS  1-16   A16   MAYS ROAD METER IDENTIFICATION CODE           MR  610
C      COLS 18-21   A4    DISTRICT / FILE IDENTIFICATION CODE           MR  620
C      COLS 23-24   I2    MAYS METER CALIBRATION VELOCITY               MR  630
C                           (DEFAULT = 50 M.P.H.)                       MR  640
C      COLS 26-41   A16   MAYS METER RUN DATE                           MR  650
C      COLS 43-50   A8    PROFILOMETER RUN DATE                         MR  660
C      COLS 52-53   I2    THE NUMBER OF RUNS PER SECTION (1 TO 10).     MR  670
C                           IF LEFT BLANK IT DEFAULTS TO 5 (IF THERE    MR  680
C                           IS A -T- IN COLUMN 55) OR 4 (IF THERE IS    MR  690
C                           NO -T- IN COLUMN 55).                       MR  700
C      COL  55       A1    A FLAG INDICATING WHETHER OR NOT ONE         MR  710
C                           OUTLYING RUN PER SECTION IS TO BE DISCARDED.MR  720
C                           (IF A -T- IS SPECIFIED, OUTLIERS WILL BE    MR  730
C                           DISCARDED; OTHERWISE NOT.)                  MR  740
C      COL  57       A1    A FLAG INDICATING WHETHER MRM VALUES INPUT ON MR  750
C                           THE RUN CARD ARE IN COUNTS OR CHART INCHES. MR  760
C                           (IF A -T- IS SPECIFIED, UNITS ARE CHART     MR  770
C                           INCHES;  OTHERWISE UNITS ARE COUNTS.)       MR  780
C                                                                       MR  790
C                                                                       MR  800
C    SECTION HEADER CARD -   FORMAT (I4,F10.0)                          MR  810
C                                                                       MR  820
C      COLS  1- 4   I4    SECTION NUMBER                                MR  830
C      COLS  5-14   F10   PROFILOMETER READING FOR THE SECTION (MO)     MR  840
C                                                                       MR  850
C                                                                       MR  860
C    RUN CARD -              FORMAT (4F10.0)                            MR  870
C                                                                       MR  880
C      COLS  1-10   F10   MRM COUNTS FOR THE FIRST .05 MILE OF SECTION  MR  890
C      COLS 11-20   F10   MRM COUNTS FOR THE SECOND .05 MILE OF SECTION MR  900
C      COLS 21-30   F10   MRM COUNTS FOR THE THIRD .05 MILE OF SECTION  MR  910
C      COLS 31-40   F10   MRM COUNTS FOR THE FOURTH .05 MILE OF SECTION MR  920
C                                                                       MR  930
C      (IF SO SPECIFIED ON THE IDENTIFICATION CARD, UNITS ARE CHART     MR  940
C      INCHES RATHER THAN COUNTS.)                                      MR  950
C                                                                       MR  960
C                                                                       MR  970
C***********************************************************************MR  980
C***********************************************************************MR  990
C                                                                       MR 1000
C  PARAMETERS AND VARIABLES IN COMMON --                                MR 1010
C                                                                       MR 1020
C    ALPHA    ADDITIVE CONSTANT IN REGRESSION EQUATION                  MR 1030
C    AMI      ARRAY OF MI (MAYS METER) VALUES                           MR 1040
C    AMO      ARRAY OF MO (PROFILOMETER) VALUES                         MR 1050
C    BETA     MULTIPLICATIVE CONSTANT IN REGRESSION EQUATION            MR 1060
C    DATEM    DATE OF MAYS METER RUN                                    MR 1070
C    DATEP    DATE OF PROFILOMETER RUN                                  MR 1080
C    DISFL    DISTRICT OR FILE NUMBER                                   MR 1090
C    IVELOC   CALIBRATION VELOCITY OF MAYS METER                        MR 1100
C    KLINES   LINE COUNTER (USED BY SUBROUTINE -PAGE-)                  MR 1110
C    KSECNO   ARRAY OF SECTION NUMBERS                                  MR 1120
C    NPAGE    PAGE COUNTER (USED BY SUBROUTINE -PAGE-)                  MR 1130
C    NSEC     NUMBER OF SECTIONS FOR WHICH MO AND MI VALUES WERE READ   MR 1140
C                                                                       MR 1150
C***********************************************************************MR 1160
C                                                                       MR 1170
```

```
C$    IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /HEAD/ DATEM(4),DISFL,MRMID(4),IVFLOC,DATEP(2),NPAGE,KLINES
      DIMENSION AMO(35), AMI(35), KSECNO(35)
C
C
C     ** SET PAGE COUNT
      NPAGE = 0
C
C     ** READ IN DATA AND ECHO-PRINT
      CALL READIN ( NSEC,KSECNO,AMO,AMI )
C
C     ** PERFORM REGRESSION AND PRINT RESULTS
      CALL LINREG ( NSEC,AMO,AMI,ALPHA,BETA )
C
C     ** PRINT CALIBRATION TABLE
      CALL CALTAB ( ALPHA,BETA )
C
C     ** PRINT RESIDUAL TABLE
      CALL RESTAB ( NSEC,KSECNO,AMO,AMI,ALPHA,BETA )
C
C     ** DO PRINTER-PLOT
      CALL PPLOT ( NSEC,AMO,AMI,ALPHA,BETA )
C
      CALL EXIT
      END
```

```
      SUBROUTINE CALTAB ( ALPHA, BETA )
C
C     ROUTINE TO PRINT THE CALIBRATION TABLE -- MI AND MCI FOR EACH
C     VALUE OF SIV FROM 0.5 TO 5.0 .
C
C***********************************************************************
C
C$    IMPLICIT REAL*8 (A-H,O-Z)
C
      CALL PAGE(0)
C
      WRITE (6,100)
100   FORMAT (1H0,30X,26X,17HCALIBRATION TABLE/
     +   1H0,30X,15X,35HMAYS METER   PREDICTED MO       SIV/
     +   1H ,30X,18X,4H(MI),10X,5H(MCI)/)
C
      DO 300 I=1,46
         SIV = 0.4 + 0.1*I
         AMCI = EXP ( 8.49331 + (-ALOG( SIV/5.0 )) ** 0.196876) / 32.0
         AMPI = AMCI * BETA + ALPHA
         WRITE (6,200) AMPI,AMCI,SIV
200      FORMAT (1H ,30X,10X,F9.1,F14.1,F13.1)
300   CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE LINREG ( NSEC, AMO, AMI, ALPHA, BETA )
C
C     ROUTINE TO PERFORM LINEAR REGRESSION OF MI AS A FUNCTION OF MO
C     AND PRINT THE RESULTS.
C
C***********************************************************************
C
C  VARIABLES USED --
C
C    ALPHA   0-ORDER REGRESSION COEFFICIENT (MPI AS A FUNCTION OF MO)
C    ALPHAP  0-ORDER REGRESSION COEFFICIENT (MCI AS A FUNCTION OF MI)
C    BETA    1-ORDER REGRESSION COEFFICIENT (MPI AS A FUNCTION OF MO)
C    BETAP   1-ORDER REGRESSION COEFFICIENT (MCI AS A FUNCTION OF MI)
C    BIG     ARTIFICIALLY HIGH VALUE
C    BOTTOM  DENOMINATOR OF BETA EQUATION (BOTTOM = XX-SX*SX*DN)
C    CIA     95 PER CENT CONFIDENCE INTERVAL FOR ALPHA
C    CIB     95 PER CENT CONFIDENCE INTERVAL FOR BETA
C    DN      INVERSE OF THE NUMBER OF OBSERVATIONS
C    RSQ     R-SQUARED
C    SE      STANDARD ERROR OF RESIDUALS
C    SEIN    STANDARD ERROR OF INTERCEPT
C    SESL    STANDARD ERROR OF SLOPE
C    SX      SUM FOR I = 1 TO NSEC OF MO(I)
C    SY      SUM FOR I = 1 TO NSEC OF MI(I)
C    T       ARRAY OF T-VALUES ADDRESSABLE BY (NSEC-19)
C    TOP     NUMERATOR OF BETA EQUATION (TOP = XY-SX*SY*DN)
C    XMAX    MAXIMUM MO VALUE
C    XMEAN   MEAN MO VALUE
C    XMIN    MINIMUM MO VALUE
C    XX      SUM FOR I = 1 TO NSEC OF MO(I)*MO(I)
C    XY      SUM FOR I = 1 TO NSEC OF MO(I)*MI(I)
C    YMAX    MAXIMUM MI VALUE
C    YMEAN   MEAN MI VALUE
C    YMIN    MINIMUM MI VALUE
C    YY      SUM FOR I = 1 TO NSEC OF MI(I)*MI(I)
C
C***********************************************************************
C
C$    IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION AMO(1), AMI(1), T(20)
      DATA BIG / 1.0E20 /
      DATA T / 2.0860, 2.0796, 2.0739, 2.0687, 2.0639, 2.0595, 2.0555,
     +         2.0518, 2.0484, 2.0452, 2.0423, 2.0395, 2.0369, 2.0345,
     +          2.0322, 2.0301, 2.0281, 2.0262, 2.0244, 2.0227 /
C
      CALL PAGE(0)
C
C     ** PRINT DESCRIPTION OF VARIABLES
      WRITE (6,10)
10    FORMAT (1H ,54X,21HREGRESSION VARIABLES:/
     +   1H0,34X,40HMO      PROFILE-DERIVED MAYSMETER SIMULAT,
     +         16HION USED AS THE /
     +   1H ,41X,42HCALIBRATION STANDARD (COUNTS PER .2 MILE)./
     +   1H0,34X,40HMI      ACTUAL RAW READINGS OF THE MAYSME,
     +         20HTER TO BE CALIBRATED/
     +   1H ,41X,21H(COUNTS PER .2 MILE)./
     +   1H0,34X,32HMPI     PREDICTED MI BASED ON MO./
     +   1H0,34X,40HMCI     PREDICTED MO BASED ON MI (CALIBRA,
     +         13HTED MAYSMETER/
     +   1H ,41X,9HREADING)./
     +   1H0,34X,40HSIV     RESCALING OF MCI TO PREDICT THE P,
```

```
     +           21HPRESENT SERVICEABILITY/
     +   1H ,41X,44HINDEX.  THE RELATIONSHIP BETWEEN MCI AND SIV WAS/
     +   1H ,41X,44HDERIVED INDEPENDENTLY OF THIS REGRESSION AND IS:/
     +   1H0,41X,49HSIV = 5.0*EXP(-(ALOG(32.0*MCI)/8.4933)**9.3566) .)
C
C      ** CLEAR SUMMATION VARIABLES
       SX = 0.0
       SY = 0.0
       XX = 0.0
       YY = 0.0
       XY = 0.0
       XMAX = -BIG
       YMAX = -BIG
       XMIN = BIG
       YMIN = BIG
C
C      ** SUMMATION LOOP
       DO 100 I=1,NSEC
          X0 = AMD(I)
          Y0 = AMT(I)
          XMIN = AMIN1 ( XMIN, X0 )
          YMIN = AMIN1 ( YMIN, Y0 )
          XMAX = AMAX1 ( XMAX, X0 )
          YMAX = AMAX1 ( YMAX, Y0 )
          SX = SX + X0
          SY = SY + Y0
          XX = XX + X0*X0
          YY = YY + Y0*Y0
          XY = XY + X0*Y0
100    CONTINUE
C
C      ** CALCULATE REGRESSION COEFFICIENTS
       DN = 1.0 / FLOAT( NSEC )
       TOP = XY - SX*SY*DN
       BOTTOM = XX - SX*SX*DN
       BETA = TOP / BOTTOM
       ALPHA = DN * ( SY - BETA*SX )
       BETAP = 1.0 / BETA
       ALPHAP = -ALPHA / BETA
       SSR = BETA * TOP
       SSE = YY - SY*SY*DN - SSR
       SE = SQRT ( SSE / (NSEC-2) )
       XMEAN = SX * DN
       YMEAN = SY * DN
       SESL = SE / SQRT(BOTTOM)
       SEIN = SE * SQRT ( XX * DN / BOTTOM )
       IF ((NSEC .LT. 20) .OR. (NSEC .GT. 40))  GO TO 110
       CIA = T(NSEC-19) * SEIN
       CIB = T(NSEC-19) * SESL
110    CONTINUE
       RSQ = SSR / ( SSE + SSR )
C
C      ** PRINT THE RESULTS
       WRITE (6,200) NSEC,XMEAN,YMEAN
       WRITE (6,210) ALPHA,BETA
       IF ((NSEC .GE. 20) .AND. (NSEC .LE. 40))
     +      WRITE (6,220) ALPHA-CIA,ALPHA+CIA,BETA-CIB,BETA+CIB
       WRITE (6,230) SEIN,SESL,RSQ,SE
       WRITE (6,240) ALPHA,BETA,ALPHAP,BETAP
200    FORMAT (1H0,30X,69(1H*)//
     +   1H0,54X,19HREGRESSION RESULTS:/
     +   1H0,44X,19HNUMBER OF SECTIONS:,9X,I11/
```

```
     +    1H ,44X,8HMEAN M0:,20X,F11.2/
     +    1H ,44X,8HMEAN M1:,20X,F11.2)
210   FORMAT (1H0,44X,6HALPHA:,22X,F11.4/
     +    1H ,44X,5HBETA:,23X,F11.4)
220   FORMAT (1H0,44X,32H95 PERCENT CONFIDENCE INTERVALS:/
     +    1H ,49X,F8.2,13H <  ALPHA  < ,F8.2/
     +    1H ,49X,F8.2,13H <  BETA   < ,F8.2)
230   FORMAT (1H0,44X,28HSTANDARD ERROR OF INTERCEPT:,F11.4/
     +    1H ,44X,24HSTANDARD ERROR OF SLOPE:,4X,F11.4/
     +    1H0,44X,10HR-SQUARED:,18X,F11.5/
     +    1H ,44X,28HSTANDARD ERROR OF RESIDUALS:,F11.4)
240   FORMAT (/1H0,44X,21HREGRESSION EQUATIONS:/
     +    1H0,47X,6HMPI  =,F11.4,3H  +,F11.4,5H * M0/
     +    1H0,47X,6HMCI  =,F11.4,3H  +,F11.4,5H * M1)
C
C
      RETURN
      END
```

```
      SUBROUTINE PAGE ( NLINES )
C
C     ROUTINE TO SKIP TO THE NEXT PAGE AND PRINT A HEADING IF DESIRED.
C
C     THE PARAMETER -NLINES- IS USED TO CONTROL PAGINATION.
C        IF NLINES = 0, THE SUBROUTINE SKIPS TO A NEW PAGE AND PRINTS
C        THE HEADER.  OTHERWISE THE LINE-COUNTER -KLINES- IS INCREMENTED
C        BY -NLINES- AND THE SUBROUTINE SKIPS TO A NEW PAGE ONLY IF
C        THE RESULT IS GREATER THAN -MAXLNS-.
C
C***********************************************************************
C
C$    IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /HEAD/ DATEM(4),DISFL,MRMID(4),IVELOC,DATEP(2),NPAGE,KLINES
      DATA MAXLNS / 60 /
C
C
      KLINES = KLINES + NLINES
      IF ((NLINES .NE. 0) .AND. (KLINES .LE. MAXLNS))  RETURN
C
C     ** PAGE EJECT
      KLINES = NLINES + 9
      NPAGE = NPAGE + 1
      WRITE (6,100) NPAGE,DISFL,IVELOC,MRMID,DATEM,DATEP
100   FORMAT ( 1H1,13X,8HTRIM--->,72X,4HPAGE,I2,7X,8H<---TRIM/
     +    1H ,37X,20HTEXAS HIGHWAY DEPARTMENT,
     +            30H - MAYS RIDE METER CALIBRATION/
     +    1H0,30X,69(1H*)/
     +    1H ,30X,15HDISTRICT/FILE: ,A4,16X,21HCALIBRATION VELOCITY:, I3,
     +            4H MPH/
     +    1H ,30X,9HMRM NO.: ,4A4,10X,19HMAYS METER RUN:    ,4A4/
     +    1H ,65X,19HPROFILOMETER RUN:  ,2A4/
     +    1H ,30X,69(1H*)/)
C
      RETURN
      END
```

```
      SUBROUTINE PPLOT ( NSEC, AMO, AMI, ALPHA, BETA )
C
C     ROUTINE TO PRODUCE A PRINTER-PLOT OF MO VS MI AND THEIR
C     REGRESSION LINE.
C
C***********************************************************************
C
C     THE APPROACH USED TO CREATE THE PRINTER-PLOT IS AS FOLLOWS:
C
C     THE ARRAY -SCREEN-, 61 BY 37, IS A 6-BY-6-INCH CHARACTER BUFFER
C     ON WHICH THE PLOT IS DRAWN.  ITS X AND Y AXES CORRESPOND TO MO
C     AND MI RESPECTIVELY.  SCALE FACTORS ARE CHOSEN SO THAT THE RANGE
C     OF MO VALUES OBSERVED MAPS ON TO THE 61 CELL-WIDTHS OF THE X
C     AXIS AND THE RANGE OF MI VALUES OBSERVED MAPS ON TO THE 37 CELL-
C     HEIGHTS OF THE Y-AXIS.
C
C     FIRST, THE PROGRAM SELECTS THE ENDPOINTS OF A SEGMENT OF THE
C     REGRESSION LINE THAT CROSSES THE RANGE OF OBSERVED POINTS. THESE
C     ENDPOINTS ARE SCALED TO SCREEN COORDINATES AND THE LINE IS THEN
C     DRAWN USING A -SIMPLE DIGITAL DIFFERENTIAL ANALYZER- ALGORITHM,
C     OR DDA, AS DESCRIBED IN -PRINCIPLES OF INTERACTIVE GRAPHICS- BY
C     NEWMAN AND SPROULL (PP. 24-25).
C
C     NEXT, THE PROGRAM PLOTS THE OBSERVED (MO,MI) POINTS BY SIMPLY
C     SCALING THEM TO SCREEN COORDINATES AND PLOTTING EACH POINT.
C
C     FINALLY, -SCREEN- IS PRINTED OUT LINE-BY-LINE, TOP LINE FIRST,
C     WITH THE AXES LABELLED WITH MO AND MI VALUES AT ONE-INCH
C     INTERVALS.
C
C***********************************************************************
C
C  VARIABLES USED --
C    AMIDEL   DIFFERENCE BETWEEN MAXIMUM AND MINIMUM VALUES OF MI
C    AMIMAX   MAXIMUM MI VALUE
C    AMIMIN   MINIMUM MI VALUE
C    AMITIC   DISTANCE BETWEEN TIC MARKS ON MI AXIS
C    AMITOY   MI TO Y CONVERSION FACTOR
C    AMI1     MI VALUE FOR FIRST ENDPOINT OF REGRESSION LINE
C    AMI2     MI VALUE FOR SECOND ENDPOINT OF REGRESSION LINE
C    AMODEL   DIFFERENCE BETWEEN MAXIMUM AND MINIMUM VALUES OF MO
C    AMOMAX   MAXIMUM MO VALUE
C    AMOMIN   MINIMUM MO VALUE
C    AMOTIC   DISTANCE BETWEEN TIC MARKS ON MO AXIS
C    AMOTOX   MO TO X CONVERSION FACTOR
C    AMO1     MO VALUE FOR FIRST ENDPOINT OF REGRESSION LINE
C    AMO2     MO VALUE FOR SECOND ENDPOINT OF REGRESSION LINE
C    DELTA    LENGTH ESTIMATE FOR REGRESSION LINE
C    DELTAX   X-AXIS LENGTH ESTIMATE FOR REGRESSION LINE
C    DELTAY   Y-AXIS LENGTH ESTIMATE FOR REGRESSION LINE
C    INCH     TIC-MARK COUNTER
C    KBLANK   CHARACTER BLANK (1H )
C    KO       CHARACTER O     (1HO)
C    KSTAR    CHARACTER STAR  (1H*)
C    NSTEPS   NUMBER OF STEPS USED TO DRAW REGRESSION LINE
C    SCREEN   61 BY 37 CHARACTER ARRAY USED FOR PLOT
C    X        X VALUE IN DDA
C    XINC     X INCREMENT IN DDA
```

```
C     X1        X VALUE FOR FIRST ENDPOINT OF REGRESSION LINE
C     X2        X VALUE FOR SECOND ENDPOINT OF REGRESSION LINE
C     Y         Y VALUE IN DDA
C     YINC      Y INCREMENT IN DDA
C     Y1        Y VALUE FOR FIRST ENDPOINT OF REGRESSION LINE
C     Y2        Y VALUE FOR SECOND ENDPOINT OF REGRESSION LINE
C
C***********************************************************************
C
C$    IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION AMO(NSEC), AMI(NSEC)
      INTEGER SCREEN (61,37)
      DATA KBLANK,KO,KSTAR / 1H ,1HO,1H* /
C
      CALL PAGE ( 0 )
C
C     ** CLEAR SCREEN
      DO 110 I=1,61
         DO 100 J=1,37
            SCREEN (I,J) = KBLANK
100      CONTINUE
110   CONTINUE
C
C     ** DETERMINE SCALE FACTORS
      AMOMIN = AMO(1)
      AMOMAX = AMO(1)
      AMIMIN = AMI(1)
      AMIMAX = AMI(1)
      DO 200 K=2,NSEC
         IF (AMO(K) .LT. AMOMIN)  AMOMIN = AMO(K)
         IF (AMO(K) .GT. AMOMAX)  AMOMAX = AMO(K)
         IF (AMI(K) .LT. AMIMIN)  AMIMIN = AMI(K)
         IF (AMI(K) .GT. AMIMAX)  AMIMAX = AMI(K)
200   CONTINUE
      AMODEL = AMOMAX - AMOMIN
      AMIDEL = AMIMAX - AMIMIN
C
C     ** SELECT END POINT OF THE REGRESSION LINE TO BE DRAWN
      AMO1 = AMOMIN
      AMO2 = AMOMAX
      AMI1 = ALPHA + BETA*AMO1
      AMI2 = ALPHA + BETA*AMO2
C     ** CONVERT TO SCREEN COORDINATES
      AMOTOX = 60.0 / AMODEL
      AMITOY = 36.0 / AMIDEL
      X1 = (AMO1 - AMOMIN) * AMOTOX
      X2 = (AMO2 - AMOMIN) * AMOTOX
      Y1 = (AMI1 - AMIMIN) * AMITOY
      Y2 = (AMI2 - AMIMIN) * AMITOY
C
C     ** SELECT X AND Y INCREMENTS FOR DDA
      DELTAX = X2 - X1
      DELTAY = Y2 - Y1
      DELTA = AMAX1 ( ABS(DELTAX), ABS(DELTAY) )
      XINC = DELTAX / DELTA
      YINC = DELTAY / DELTA
C
C     ** PERFORM THE ITERATIVE PART OF THE DDA PROCESS: STEP ALONG LINE
      X = X1 + 1.5
      Y = Y1 + 1.5
      NSTEPS = INT(DELTA) + 5
      DO 300 K=1,NSTEPS
```

```
         I = INT(X)
         J = INT(Y)
C        ** PLOT POINT ON LINE (UNLESS CLIPPED)
         IF ((I.GE.1).AND.(I.LE.61).AND.(J.GE.1).AND.(J.LE.37))
     +                        SCREEN (I,J) = KSTAR
         X = X + XINC
         Y = Y + YINC
300   CONTINUE
C
C     ** PLOT (MO,MI) POINTS
      DO 400 K=1,NSEC
         I = INT( (AMO(K) - AMOMIN) * AMOTOX + 1.5 )
         J = INT( (AMI(K) - AMIMIN) * AMITOY + 1.5 )
         SCREEN (I,J) = KO
400   CONTINUE
C
C     ** PRINT THE SCREEN
      AMOTIC = 10.0 / 60.0 * AMODEL
      AMITIC =  6.0 / 36.0 * AMIDEL
      WRITE (6,520) ALPHA,BETA
      WRITE (6,530) AMIMAX,(SCREEN(I,37),I=1,61)
      DO 510 INCH=1,6
         DO 500 JJ=1,5
            I = 43 - 6*INCH - JJ
            WRITE (6,540) (SCREEN(I,J),I=1,61)
500      CONTINUE
         J = 37 - 6*INCH
         WRITE (6,530) AMIMAX-INCH*AMITIC,(SCREEN(I,J),I=1,61)
510   CONTINUE
      WRITE (6,550) (AMOMIN+(INCH-1)*AMOTIC,INCH=1,7)
520   FORMAT (/1H0,42X,45HPLOT OF MO VS. MI (INCLUDING REGRESSION LINE)/
     +   1H0,42X,7HALPHA =,F10.4,12X,6HBETA =,F10.4/
     +   1H0,36X,2H+:,6(10H+++++++++:),1H+)
530   FORMAT (1H ,30X,F6.1,1H:,61A1,1H:)
540   FORMAT (1H ,36X,1H+,61A1,1H+)
550   FORMAT (1H ,36X,2H+:,6(10H+++++++++:),1H+/
     +   1H ,29X,7F10.1/
     +   1H0,40X,17HVERTICAL AXIS: MI,13X,19HHORIZONTAL AXIS: MO/
     +   1H0,54X,16HO  -  DATA POINT/
     +   1H ,54X,21H*  -  REGRESSION LINE)
C
      RETURN
      END
```

```
      SUBROUTINE READIN ( NSEC, KSECNO, AMO, AMI )
C
C     ROUTINE TO READ IN AND ECHO-PRINT THE REGRESSION DATA.
C
C***********************************************************************
C
C$    IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /HEAD/ DATEM(4),DISFL,MRMID(4),IVELOC,DATEP(2),NPAGE,KLINES
      DIMENSION KSECNO(1),AMO(1),AMI(1),RAWDAT(10,4),RUNTOT(10)
      LOGICAL THROW,CHART
      DATA KT / 1HT /
C
C     ** READ IDENTIFICATION INFORMATION
```

```
      READ (5,100) MRMID,DISFL,IVELOC,DATEM,DATEP,NRUNS,KTHROW,KCHART
100   FORMAT (4A4,X,A4,X,I2,X,4A4,X,2A4,X,I2,X,A1,X,A1)
C     ** SET OUTLIER AND MRM UNITS FLAGS (-THROW- AND -CHART-)
      THROW = .FALSE.
      IF (KTHROW .EQ. KT)  THROW = .TRUE.
      CHART = .FALSE.
      IF (KCHART .EQ. KT)  CHART = .TRUE.
C     ** SET DEFAULT VALUE OF NRUNS
      IF (NRUNS .GT. 10)  STOP 1
      IF ((NRUNS .LE. 0) .AND. (.NOT. THROW))  NRUNS = 4
      IF ((NRUNS .LE. 0) .AND.      THROW     )  NRUNS = 5
C     ** SET DEFAULT VALUE OF IVELOC
      IF (IVELOC .LE. 0)  IVELOC = 50
C
C     ** PRINT PAGE HEADER
      CALL PAGE ( 0 )
      CALL PAGE ( 8 )
      WRITE (6,150) NRUNS
      IF (THROW)  WRITE (6,160)
      IF (.NOT. THROW)  WRITE (6,170)
      IF (CHART)  WRITE (6,180)
      IF (.NOT. CHART)  WRITE (6,190)
150   FORMAT (/1H0,53X,21HI N P U T   D A T A 1/
     +   1H0,38X,9HTHERE ARE,I3,18H RUNS PER SECTION.)
160   FORMAT (1H ,38X,37HONE OUTLYING RUN PER SECTION WILL BE ,
     +                  10HDISCARDED.)
170   FORMAT (1H ,38X,36HOUTLYING RUNS WILL NOT BE DISCARDED.)
180   FORMAT (1H ,38X,40HMAYS METER INPUT UNITS ARE CHART INCHES./)
190   FORMAT (1H ,38X,34HMAYS METER INPUT UNITS ARE COUNTS./)
C
C     ** LOOP TO READ AND PROCESS DATA SECTION BY SECTION
      NSEC = 0
200   CONTINUE
         NSEC = NSEC + 1
         READ (5,210,END=400) KSECNO(NSEC),AMO(NSEC),
     +                        ((RAWDAT(I,J),J=1,4),I=1,NRUNS)
210      FORMAT (I4,F10.0,/(4F10.0))
C
C        ** CALCULATE THE TOTAL MAYS METER READING FOR EACH RUN
         DO 220 I=1,NRUNS
            RUNTOT(I) = RAWDAT(I,1)+RAWDAT(I,2)+RAWDAT(I,3)+RAWDAT(I,4)
220      CONTINUE
C
C        ** CALCULATE AMI(NSEC), ELIMINATING THE OUTLYING RUN IF NECESSA
         TOT = 0.0
         DO 230 I=1,NRUNS
            TOT = TOT + RUNTOT(I)
230      CONTINUE
         TEMPMI = TOT / FLOAT(NRUNS)
         NOUTL = 0
         IF (.NOT. THROW)  GO TO 250
         NOUTL = 1
         DO 240 I=2,NRUNS
            IF (ABS(RUNTOT(I)-TEMPMI) .GT. ABS(RUNTOT(NOUTL)-TEMPMI))
     +                             NOUTL = I
240      CONTINUE
         TEMPMI = (TOT - RUNTOT(NOUTL)) / 4.0
250      AMI(NSEC) = TEMPMI
         IF (CHART)  AMI(NSEC) = AMI(NSEC) * 32.0
C
C        ** PRINT DATA FOR SECTION
         CALL PAGE ( NRUNS+3 )
```

```
          WRITE (6,300) KSECNO(NSEC),AMO(NSEC),AMI(NSEC)
300       FORMAT (1H0,38X,14HSECTION NUMBER,I4,8H    MO =,F8.2,
     +            8H    MI =,F8.2/)
          DO 330 I=1,NRUNS
             WRITE (6,310) (RAWDAT(I,J),J=1,4),RUNTOT(I)
310          FORMAT (51X,3(F6.1,2H +),F6.1,2H =,F6.1)
             IF (I .EQ. NOUTL)  WRITE (6,320)
320          FORMAT (1H+,89X,9H(OUTLIER))
330       CONTINUE
C
C      ** END-OF-LOOP
       IF (NSEC .LT. 35)  GO TO 200
C
C      ** TOO MANY SECTIONS
       WRITE (6,350) NSEC
350    FORMAT (1H0,38X,4HONLY,I3,17H SECTIONS READ --/
     +         1H ,38X,32HANY ADDITIONAL SECTIONS IGNORED.)
       RETURN
C
C
C      ** NORMAL LOOP EXIT (END-OF-FILE)
400    CONTINUE
       NSEC = NSEC - 1
       RETURN
       END
```

```
       SUBROUTINE RESTAB ( NSEC, KSECNO, AMO, AMI, ALPHA, BETA )
C
C      ROUTINE TO PRINT THE RESIDUAL TABLE -- SECTION NUMBER,
C      MI, MO, MCI, AND MCI-MO FOR EACH SECTION.
C
C***********************************************************************
C
C$     IMPLICIT REAL*8 (A-H,O-Z)
       DIMENSION KSECNO(1),AMO(1),AMI(1)
C
       CALL PAGE(0)
C
       WRITE (6,100)
100    FORMAT (/1H0,57X,14HRESIDUAL TABLE/
     +    1H0,37X,40HSECTION   MAYS METER   EXPECTED   PREDIC,
     +                 10HTED   RESIDUAL/
     +    1H ,38X,6HNUMBER,6X,4H(MI),9X,2HMO,6X,9HMO  (MCI),6X,2HMO/)
C
       DO 300 I=1,NSEC
          AMCI = (AMI(I) - ALPHA) / BETA
          RES = AMCI - AMO(I)
          WRITE (6,200) KSECNO(I),AMI(I),AMO(I),AMCI,RES
200       FORMAT (1H ,38X,I4,F12.1,F12.1,F12.1,F11.1)
300    CONTINUE
C
       RETURN
       END
```

```
                                                                    PAGE 1
          TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

****************************************************************************
DISTRICT/FILE:     7                     CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                       MAYS METER RUN:     01/23-25/80
                                         PROFILOMETER RUN:  JAN 80
****************************************************************************


                          I N P U T   D A T A :

          THERE ARE  4 RUNS PER SECTION.
          OUTLYING RUNS WILL NOT BE DISCARDED.
          MAYS METER INPUT UNITS ARE COUNTS.

          SECTION NUMBER  19     MO =   69.22     MI =   29.00

                           3.0 +   6.0 +  13.0 +   8.0 =  30.0
                           6.0 +   7.0 +  10.0 +   5.0 =  28.0
                           4.0 +   6.0 +  15.0 +   3.0 =  28.0
                           2.0 +   8.0 +  14.0 +   6.0 =  30.0

          SECTION NUMBER  45     MO =  140.11     MI =  263.50

                          73.0 +  71.0 +  77.0 +  26.0 = 247.0
                          69.0 +  82.0 +  71.0 +  36.0 = 258.0
                          73.0 +  87.0 +  84.0 +  33.0 = 277.0
                          77.0 +  83.0 +  84.0 +  28.0 = 272.0

          SECTION NUMBER  44     MO =  210.00     MI =  104.75

                          31.0 +  29.0 +  25.0 +  23.0 = 108.0
                          28.0 +  29.0 +  24.0 +  24.0 = 105.0
                          27.0 +  25.0 +  27.0 +  22.0 = 101.0
                          29.0 +  31.0 +  24.0 +  21.0 = 105.0

          SECTION NUMBER  41     MO =  129.16     MI =  143.50

                          39.0 +  36.0 +  40.0 +  28.0 = 143.0
                          37.0 +  38.0 +  36.0 +  31.0 = 142.0
                          37.0 +  37.0 +  39.0 +  33.0 = 146.0
                          42.0 +  31.0 +  37.0 +  33.0 = 143.0

          SECTION NUMBER  43     MO =  154.85     MI =  112.00

                          20.0 +  25.0 +  34.0 +  30.0 = 109.0
                          26.0 +  24.0 +  39.0 +  27.0 = 116.0
                          23.0 +  22.0 +  37.0 +  31.0 = 113.0
                          23.0 +  19.0 +  38.0 +  30.0 = 110.0

          SECTION NUMBER   9     MO =   59.20     MI =   36.50

                           4.0 +   7.0 +  14.0 +  10.0 =  35.0
                           9.0 +   9.0 +  10.0 +  10.0 =  38.0
                          11.0 +   7.0 +  13.0 +   8.0 =  39.0
                          11.0 +   8.0 +   7.0 +   8.0 =  34.0
```

```
                                                                 PAGE 2
          TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

**********************************************************************
DISTRICT/FILE:    7                   CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                    MAYS METER RUN:    01/23-25/80
                                      PROFILOMETER RUN:  JAN 80
**********************************************************************


        SECTION NUMBER  40     MO =    55.56     MI =    25.00

                        6.0 +    8.0 +    5.0 +    7.0 =  26.0
                       10.0 +    4.0 +    6.0 +    5.0 =  25.0
                        7.0 +    3.0 +    4.0 +    7.0 =  21.0
                        8.0 +    5.0 +    4.0 +   11.0 =  28.0

        SECTION NUMBER  39     MO =   215.30     MI =   215.25

                       44.0 +   32.0 +   82.0 +   58.0 = 216.0
                       41.0 +   31.0 +   78.0 +   60.0 = 210.0
                       43.0 +   35.0 +   76.0 +   56.0 = 210.0
                       51.0 +   33.0 +   79.0 +   62.0 = 225.0

        SECTION NUMBER  38     MO =   123.59     MI =    98.75

                       27.0 +   21.0 +   27.0 +   26.0 = 101.0
                       23.0 +   29.0 +   24.0 +   21.0 =  97.0
                       25.0 +   27.0 +   27.0 +   20.0 =  99.0
                       28.0 +   22.0 +   28.0 +   20.0 =  98.0

        SECTION NUMBER  12     MO =    64.45     MI =    35.00

                       11.0 +    6.0 +    7.0 +    9.0 =  33.0
                       11.0 +    7.0 +    5.0 +   15.0 =  38.0
                       11.0 +    7.0 +    5.0 +   10.0 =  33.0
                       12.0 +    9.0 +    6.0 +    9.0 =  36.0

        SECTION NUMBER  32     MO =    22.64     MI =    11.00

                        3.0 +    5.0 +    1.0 +    2.0 =  11.0
                        1.0 +    3.0 +    1.0 +    4.0 =   9.0
                        1.0 +    5.0 +    2.0 +    4.0 =  12.0
                        1.0 +    4.0 +    1.0 +    6.0 =  12.0

        SECTION NUMBER  10     MO =    35.49     MI =    18.50

                        3.0 +    3.0 +    8.0 +    7.0 =  21.0
                        2.0 +    8.0 +    2.0 +    5.0 =  17.0
                        1.0 +    5.0 +    8.0 +    4.0 =  18.0
                        1.0 +    3.0 +    6.0 +    8.0 =  18.0

        SECTION NUMBER  13     MO =   103.28     MI =    84.50

                       17.0 +   16.0 +   17.0 +   33.0 =  83.0
                       15.0 +   17.0 +   19.0 +   37.0 =  88.0
                       15.0 +   17.0 +   19.0 +   31.0 =  82.0
                       20.0 +   16.0 +   20.0 +   29.0 =  85.0
```

```
                                                                       PAGE 3
       TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

*******************************************************************************
DISTRICT/FILE:    7                        CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                         MAYS METER RUN:    01/23-25/80
                                           PROFILOMETER RUN:  JAN 80
*******************************************************************************


         SECTION NUMBER  14     MO =   65.66     MI =   37.00

                        12.0 +  10.0 +   9.0 +   6.0 =  37.0
                        13.0 +  10.0 +   9.0 +   6.0 =  38.0
                        13.0 +   9.0 +   6.0 +   7.0 =  35.0
                        12.0 +   8.0 +   9.0 +   9.0 =  38.0

         SECTION NUMBER  15     MO =   64.99     MI =   48.25

                        18.0 +  12.0 +   8.0 +   9.0 =  47.0
                        16.0 +  18.0 +   6.0 +   7.0 =  47.0
                        20.0 +  13.0 +   6.0 +  14.0 =  53.0
                        21.0 +  11.0 +   8.0 +   6.0 =  46.0

         SECTION NUMBER  37     MO =  119.85     MI =   85.50

                        28.0 +  21.0 +  14.0 +  12.0 =  75.0
                        32.0 +  26.0 +  13.0 +  29.0 = 100.0
                        26.0 +  28.0 +  13.0 +  21.0 =  88.0
                        30.0 +  23.0 +  16.0 +  10.0 =  79.0

         SECTION NUMBER  36     MO =   53.19     MI =   40.25

                         8.0 +  11.0 +  12.0 +  12.0 =  43.0
                         8.0 +  16.0 +   7.0 +   8.0 =  39.0
                         9.0 +  12.0 +  12.0 +  10.0 =  43.0
                        10.0 +   8.0 +   9.0 +   9.0 =  36.0

         SECTION NUMBER  35     MO =  195.26     MI =  140.50

                        31.0 +  35.0 +  37.0 +  30.0 = 133.0
                        28.0 +  38.0 +  38.0 +  40.0 = 144.0
                        27.0 +  39.0 +  36.0 +  39.0 = 141.0
                        31.0 +  37.0 +  39.0 +  37.0 = 144.0

         SECTION NUMBER   8     MO =   59.03     MI =   53.75

                        18.0 +  15.0 +  11.0 +   8.0 =  52.0
                        16.0 +  14.0 +  14.0 +  10.0 =  54.0
                        16.0 +  13.0 +  11.0 +  11.0 =  51.0
                        17.0 +  14.0 +  12.0 +  15.0 =  58.0

         SECTION NUMBER   5     MO =   18.53     MI =   14.25

                         2.0 +   3.0 +   3.0 +   7.0 =  15.0
                         3.0 +   2.0 +   3.0 +   6.0 =  14.0
                         6.0 +   3.0 +   2.0 +   3.0 =  14.0
                         4.0 +   3.0 +   1.0 +   6.0 =  14.0
```

```
                                                                    PAGE 4
        TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

*****************************************************************************
DISTRICT/FILE:    7                     CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                      MAYS METER RUN:    01/23-25/80
                                        PROFILOMETER RUN:  JAN 80
*****************************************************************************


        SECTION NUMBER   3     MO =   52.87     MI =   32.75

                       14.0 +   6.0 +   6.0 +   7.0 =  33.0
                        6.0 +  13.0 +   5.0 +   6.0 =  30.0
                        7.0 +  10.0 +   5.0 +   9.0 =  31.0
                       10.0 +  13.0 +   5.0 +   9.0 =  37.0

        SECTION NUMBER   6     MO =  103.02     MI =   68.00

                       20.0 +  15.0 +  22.0 +  16.0 =  73.0
                       21.0 +  14.0 +  17.0 +  12.0 =  64.0
                       23.0 +  13.0 +  17.0 +  14.0 =  67.0
                       23.0 +  13.0 +  16.0 +  16.0 =  68.0

        SECTION NUMBER   2     MO =  185.56     MI =  130.25

                       35.0 +  27.0 +  27.0 +  42.0 = 131.0
                       35.0 +  29.0 +  29.0 +  41.0 = 134.0
                       36.0 +  27.0 +  21.0 +  40.0 = 124.0
                       36.0 +  33.0 +  21.0 +  42.0 = 132.0

        SECTION NUMBER   7     MO =   11.83     MI =   10.50

                        2.0 +   3.0 +   2.0 +   1.0 =   8.0
                        2.0 +   2.0 +   1.0 +   5.0 =  10.0
                        2.0 +   3.0 +   2.0 +   4.0 =  11.0
                        4.0 +   2.0 +   3.0 +   4.0 =  13.0

        SECTION NUMBER  23     MO =  102.89     MI =   73.75

                       31.0 +  12.0 +  14.0 +  16.0 =  73.0
                       31.0 +  16.0 +  15.0 +  13.0 =  75.0
                       28.0 +  14.0 +  15.0 +  16.0 =  73.0
                       32.0 +  12.0 +  16.0 +  14.0 =  74.0

        SECTION NUMBER   1     MO =   85.05     MI =   49.50

                       11.0 +  11.0 +   9.0 +  20.0 =  51.0
                       10.0 +  13.0 +   8.0 +  14.0 =  45.0
                       12.0 +  13.0 +   9.0 +  19.0 =  53.0
                       12.0 +  11.0 +   8.0 +  18.0 =  49.0

        SECTION NUMBER  28     MO =   45.74     MI =   30.25

                        8.0 +   5.0 +   7.0 +  12.0 =  32.0
                        7.0 +   4.0 +  10.0 +  10.0 =  31.0
                        5.0 +   3.0 +   7.0 +  13.0 =  28.0
                        7.0 +   5.0 +   8.0 +  10.0 =  30.0
```

```
                                                                   PAGE 5
        TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

*******************************************************************
DISTRICT/FILE:     7                  CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                    MAYS METER RUN:    01/23-25/80
                                      PROFILOMETER RUN:  JAN 80
*******************************************************************

                         REGRESSION VARIABLES:

    MO      PROFILE-DERIVED MAYSMETER SIMULATION USED AS THE
            CALIBRATION STANDARD (COUNTS PER .2 MILE).

    MI      ACTUAL RAW READINGS OF THE MAYSMETER TO BE CALIBRATED
            (COUNTS PER .2 MILE).

    MPI     PREDICTED MI BASED ON MO.

    MCI     PREDICTED MO BASED ON MI (CALIBRATED MAYSMETER
            READING).

    SIV     RESCALING OF MCI TO PREDICT THE PRESENT SERVICEABILITY
            INDEX.  THE RELATIONSHIP BETWEEN MCI AND SIV WAS
            DERIVED INDEPENDENTLY OF THIS REGRESSION AND IS:

            SIV = 5.0*EXP(-(ALOG(32.0+MCI)/8.4933)**9.3566) .

*******************************************************************

                         REGRESSION RESULTS:

               NUMBER OF SECTIONS:                     27
               MEAN MO:                            101.57
               MEAN MI:                             73.77

               ALPHA:                             -6.6251
               BETA:                                .7915

               95 PERCENT CONFIDENCE INTERVALS:
                      -19.62 <  ALPHA  <      6.37
                         .69 <  BETA   <       .89

               STANDARD ERROR OF INTERCEPT:        6.3333
               STANDARD ERROR OF SLOPE:             .0505

               R-SQUARED:                          .90778
               STANDARD ERROR OF RESIDUALS:       19.3363

               REGRESSION EQUATIONS:

                  MPI  =     -6.6251  +       .7915 * MO

                  MCI  =      8.3706  +      1.2635 * MI
```

TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

```
*************************************************************************
DISTRICT/FILE:     7                  CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                    MAYS METER RUN:    01/23-25/80
                                      PROFILOMETER RUN:  JAN 80
*************************************************************************
```

CALIBRATION TABLE

MAYS METER (MI)	PREDICTED MO (MCI)	SIV
259.9	336.8	.5
239.1	310.4	.6
221.5	288.3	.7
206.5	269.2	.8
193.2	252.8	.9
181.5	237.6	1.0
170.8	223.2	1.1
161.2	212.0	1.2
152.3	200.8	1.3
144.1	190.8	1.4
136.5	180.9	1.5
129.4	171.9	1.6
122.8	163.5	1.7
116.5	155.6	1.8
110.6	148.1	1.9
105.0	141.0	2.0
99.6	134.2	2.1
94.5	127.8	2.2
89.6	121.6	2.3
85.0	115.7	2.4
80.5	110.1	2.5
76.2	104.7	2.6
72.1	99.4	2.7
68.0	94.3	2.8
64.2	89.4	2.9
60.4	84.7	3.0
56.8	80.1	3.1
53.2	75.6	3.2
49.8	71.3	3.3
46.4	67.0	3.4
43.2	62.9	3.5
39.9	58.8	3.6
36.8	54.9	3.7
33.7	51.0	3.8
30.7	47.1	3.9
27.7	43.4	4.0
24.7	39.6	4.1
21.8	35.9	4.2
18.9	32.2	4.3
16.0	28.5	4.4
13.0	24.8	4.5
10.0	21.1	4.6
7.0	17.2	4.7
3.7	13.0	4.8
.0	8.4	4.9
-6.6	.0	5.0

```
                                                                        PAGE 7
      TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

*****************************************************************************
DISTRICT/FILE:    7                    CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                     MAYS METER RUN:    01/23-25/80
                                       PROFILOMETER RUN:  JAN 80
*****************************************************************************


                             RESIDUAL TABLE

        SECTION    MAYS METER    EXPECTED     PREDICTED     RESIDUAL
        NUMBER        (MI)          MO        MO  (MCI)        MO

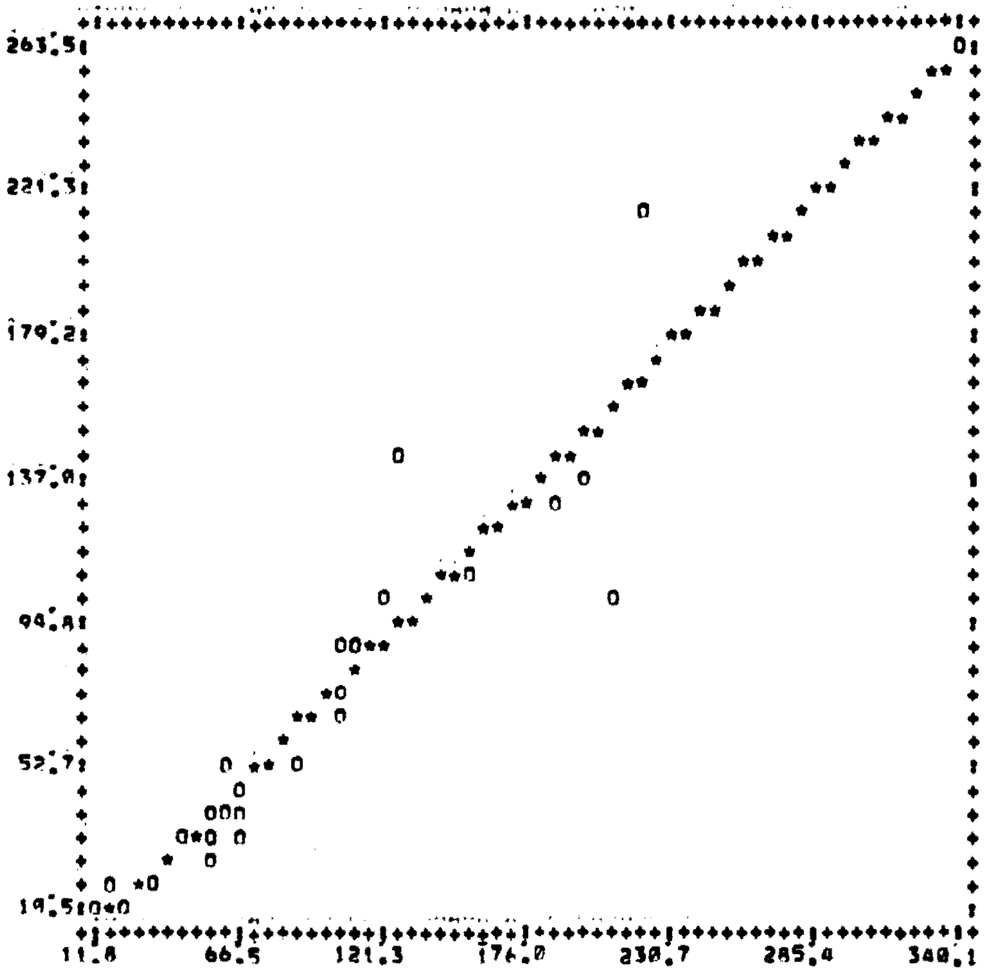
          19          29.0          69.2          45.0        -24.2
          45         263.5         340.1         341.3          1.2
          44         104.8         210.9         140.7        -70.2
          41         143.5         129.2         189.7         60.5
          43         112.0         154.9         149.9         -5.0
           9          36.5          59.2          54.5         -4.7
          40          25.0          55.6          40.0        -15.6
          39         215.3         218.3         280.3         62.0
          38          98.8         123.6         133.1          9.5
          12          35.0          64.4          52.6        -11.9
          32          11.0          22.6          22.3          -.4
          10          18.5          35.5          31.7         -3.7
          13          84.5         103.3         115.1         11.9
          14          37.0          65.7          55.1        -10.5
          15          48.3          65.0          69.3          4.3
          37          85.5         110.8         116.4          5.5
          36          40.3          93.2          99.2          6.0
          35         140.5         195.3         185.9         -9.4
           8          53.8          59.0          76.3         17.3
           5          14.3          18.5          26.4          7.8
           3          32.8          52.9          49.7         -3.1
           6          68.0         103.4          94.3         -9.1
           2         130.3         185.6         172.9        -12.6
           7          10.5          11.8          21.6          9.8
          23          73.8         102.9         101.6         -1.3
           1          49.5          85.9          70.9        -15.0
          28          30.3          45.7          46.6           .9
```

```
                                                                      PAGE 8
      TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION

*****************************************************************************
DISTRICT/FILE:    7                   CALIBRATION VELOCITY: 50 MPH
MRM NO.: 07-9873-A                    MAYS METER RUN:    01/23-25/80
                                      PROFILOMETER RUN:  JAN 80
*****************************************************************************


            PLOT OF MO VS. MI (INCLUDING REGRESSION LINE)

            ALPHA =   -6.6251              BETA =     .7915
```

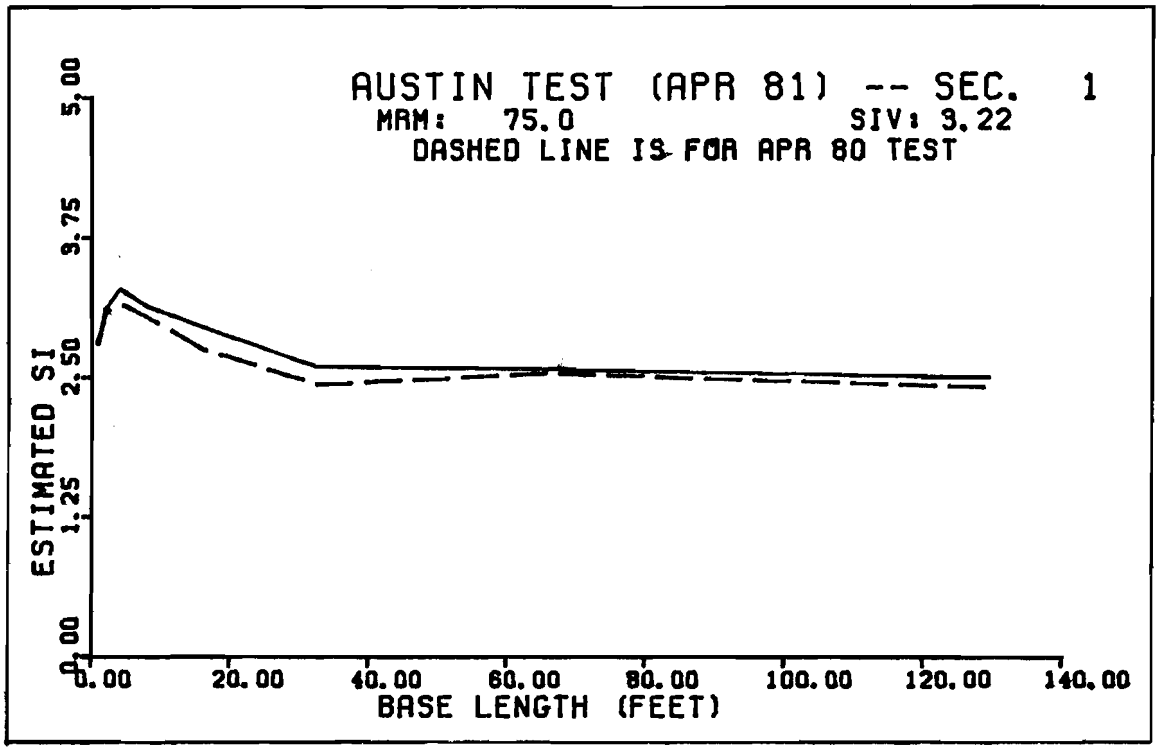


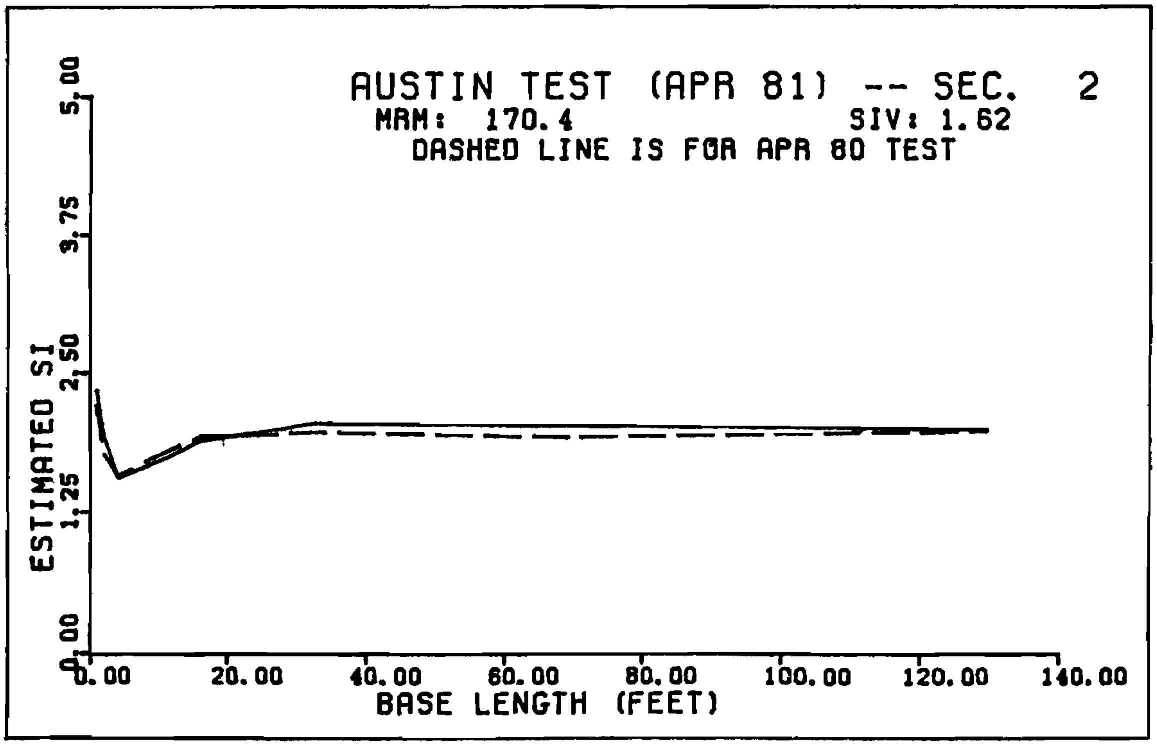
```
        VERTICAL AXIS: MI              HORIZONTAL AXIS: MO

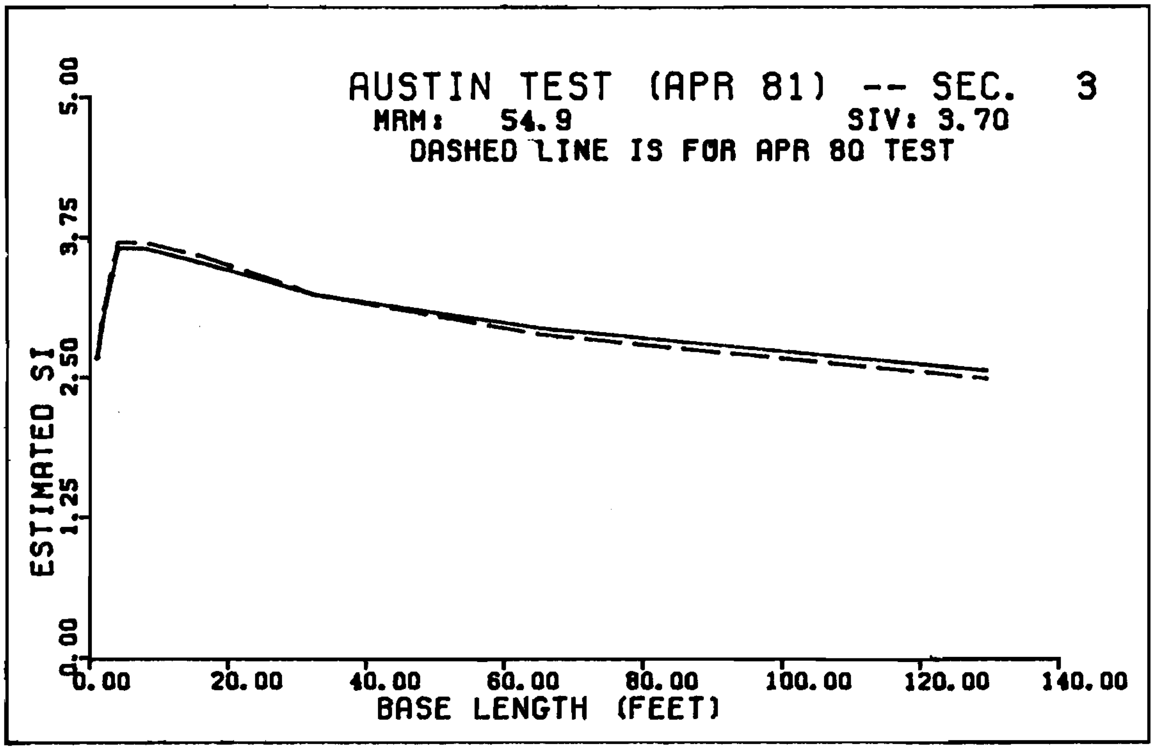
                        O  -  DATA POINT
                        *  -  REGRESSION LINE
```

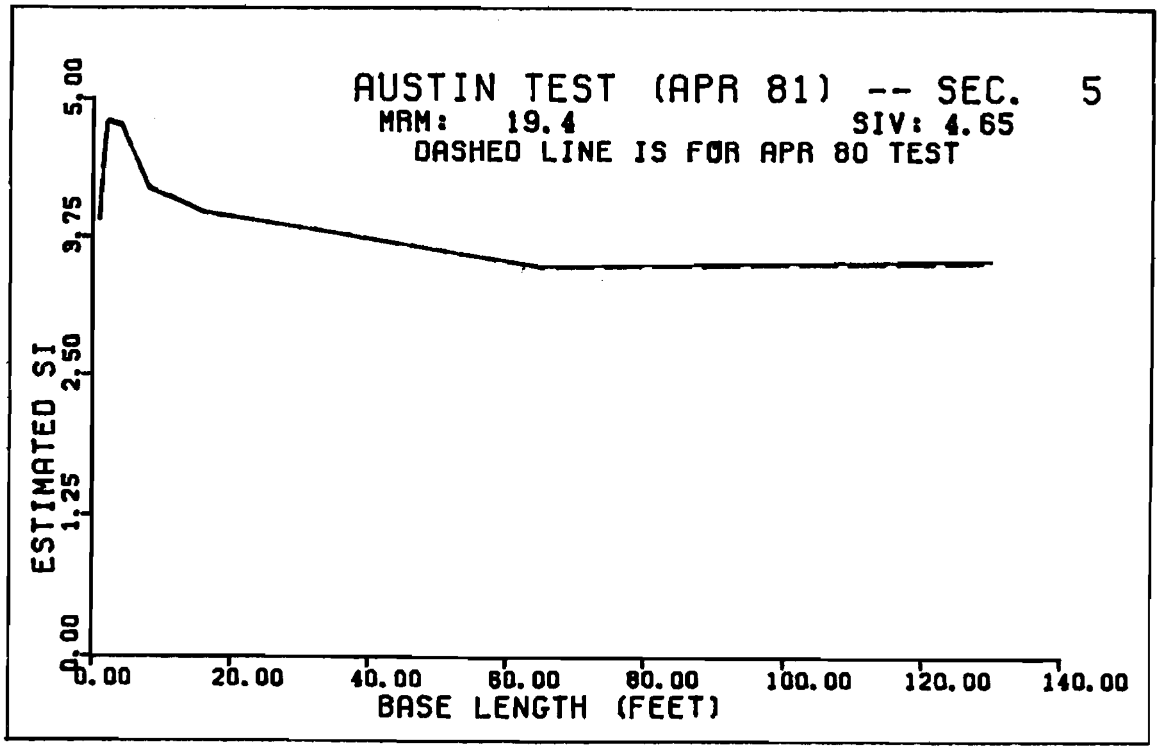
APPENDIX D

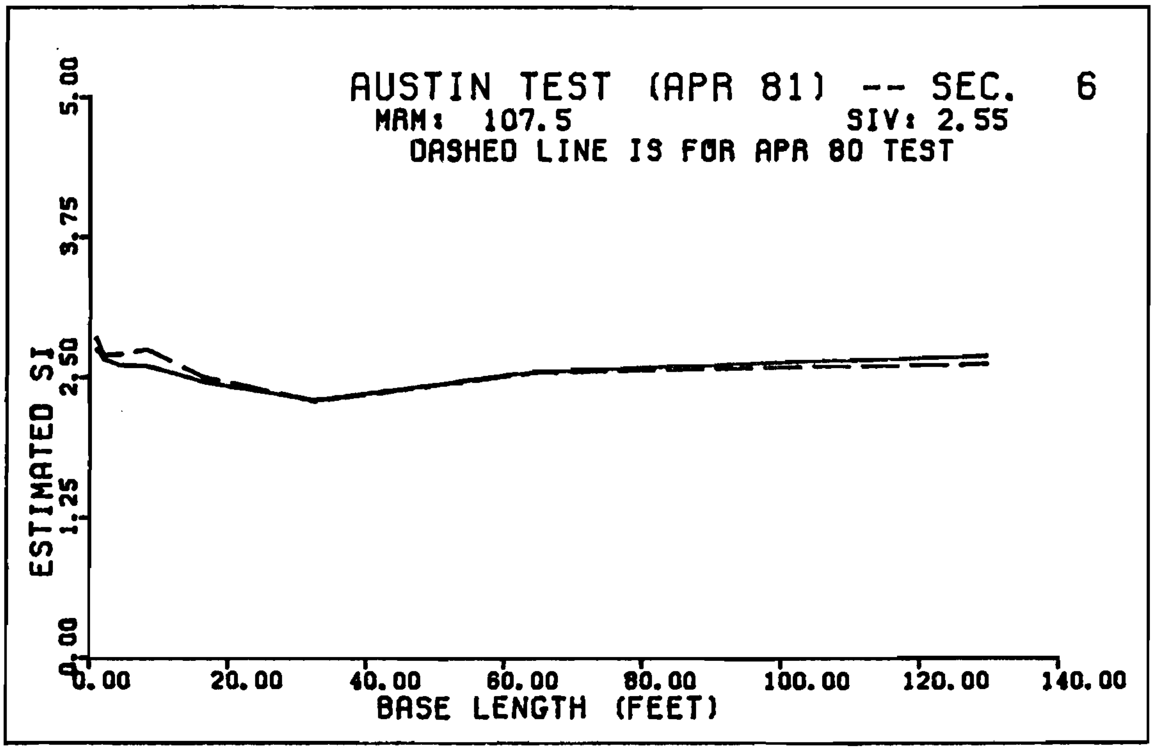
RMSVA ROUGHNESS SIGNATURES OF THE AUSTIN TEST SECTIONS

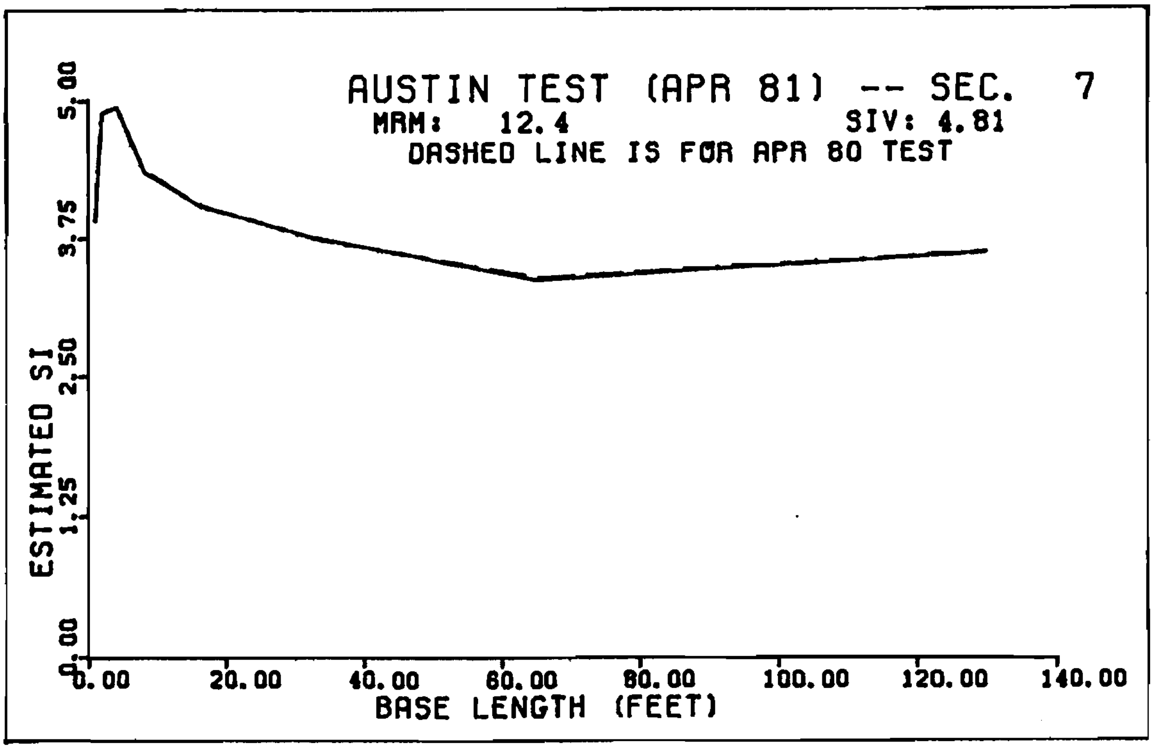

AUSTIN TEST (APR 81) -- SEC. 1
MRM: 75.0
SIV: 3.22
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)

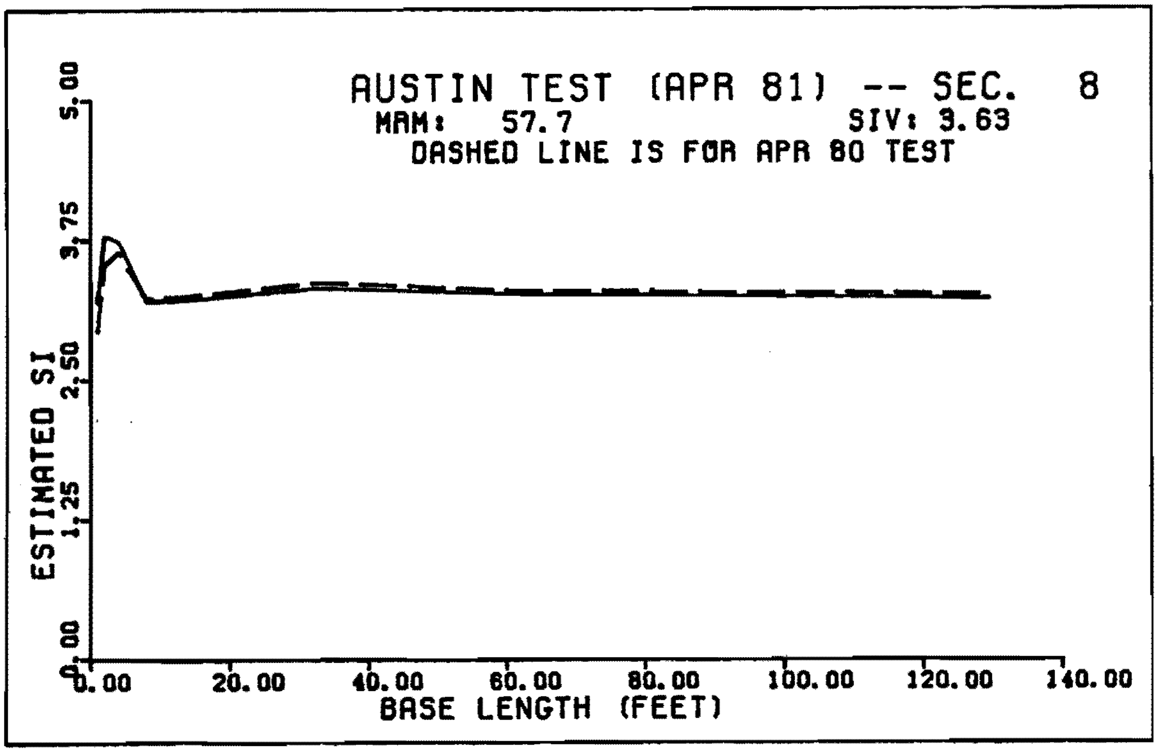

AUSTIN TEST (APR 81) -- SEC. 2
MRM: 170.4
SIV: 1.62
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)

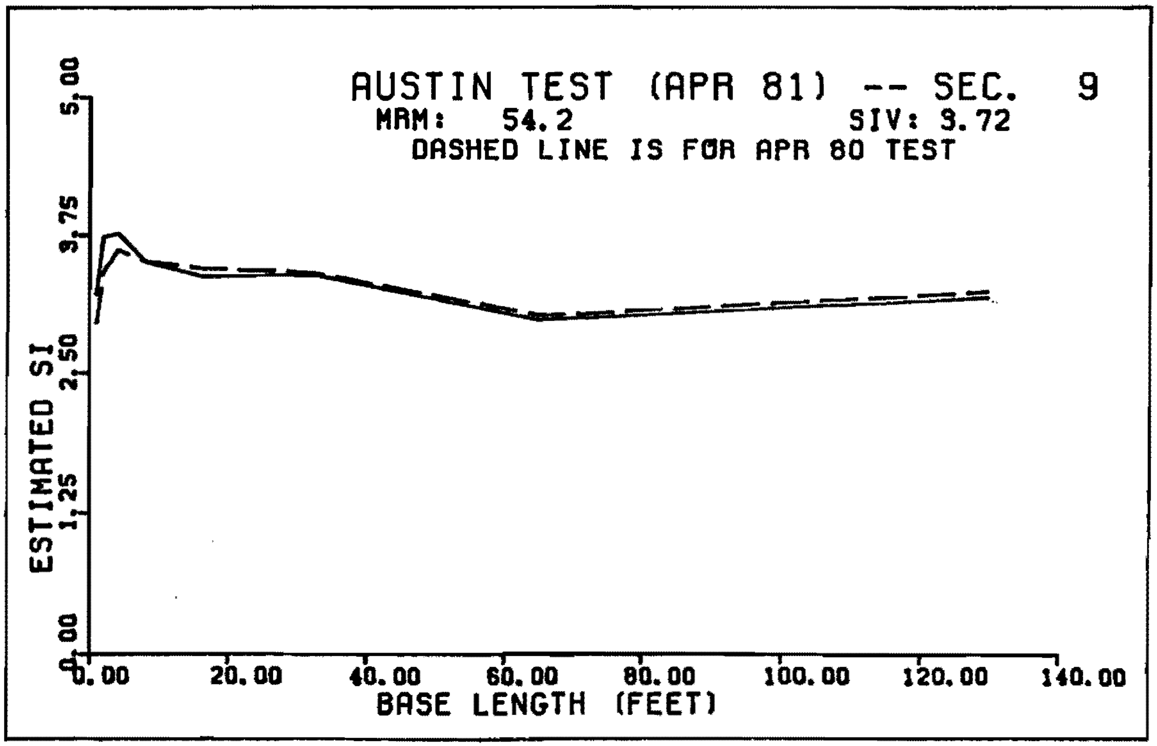

AUSTIN TEST (APR 81) -- SEC. 3
MRM: 54.9
SIV: 3.70
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 5
MRM: 19.4
SIV: 4.65
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 6
MRM: 107.5
SIV: 2.55
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 7
MRM: 12.4
SIV: 4.81
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 8
MAM: 57.7
SIV: 3.63
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 9
MAM: 54.2
SIV: 3.72
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
0.00
1.25
2.50
3.75
5.00
0.00
20.00
40.00
60.00
80.00
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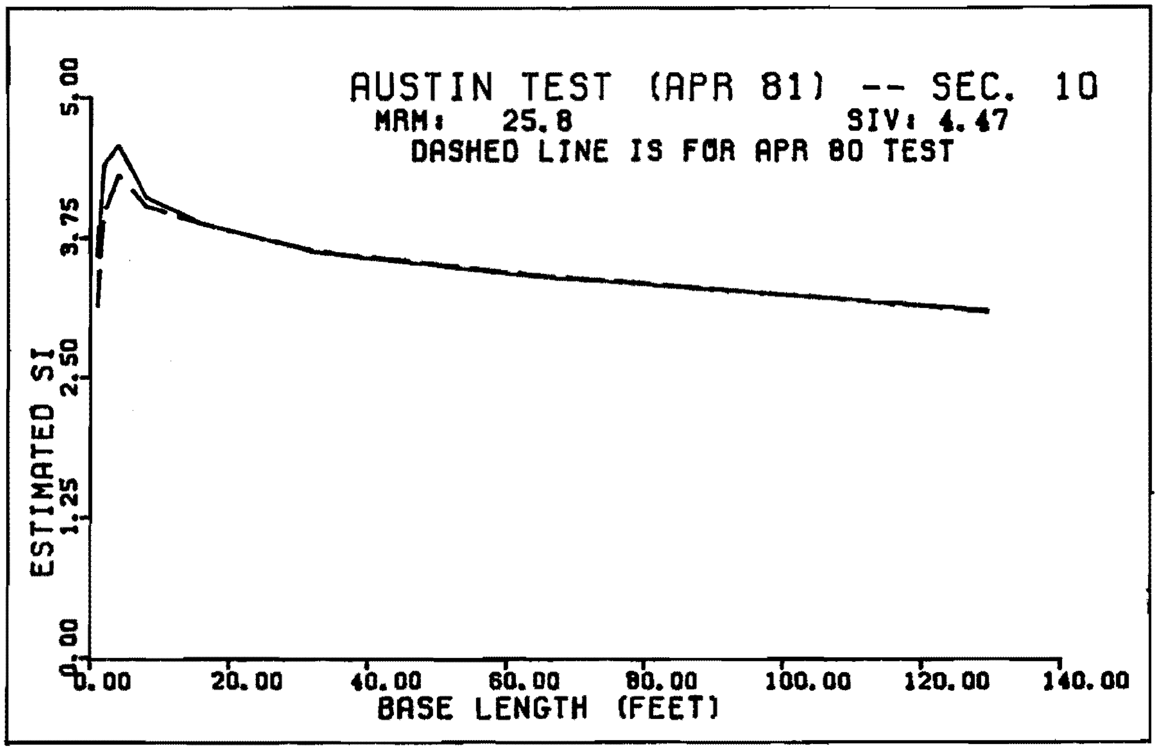
AUSTIN TEST (APR 81) -- SEC. 10
MRM: 25.8
SIV: 4.47
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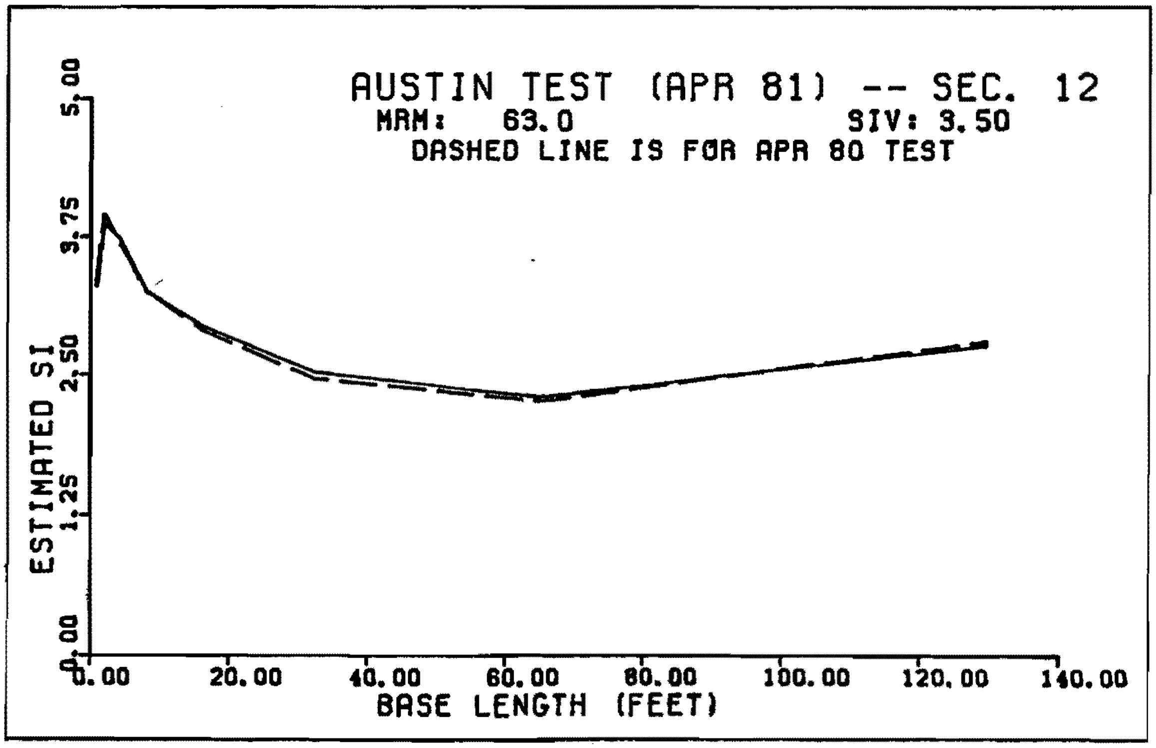
AUSTIN TEST (APR 81) -- SEC. 12
MRM: 63.0
SIV: 3.50
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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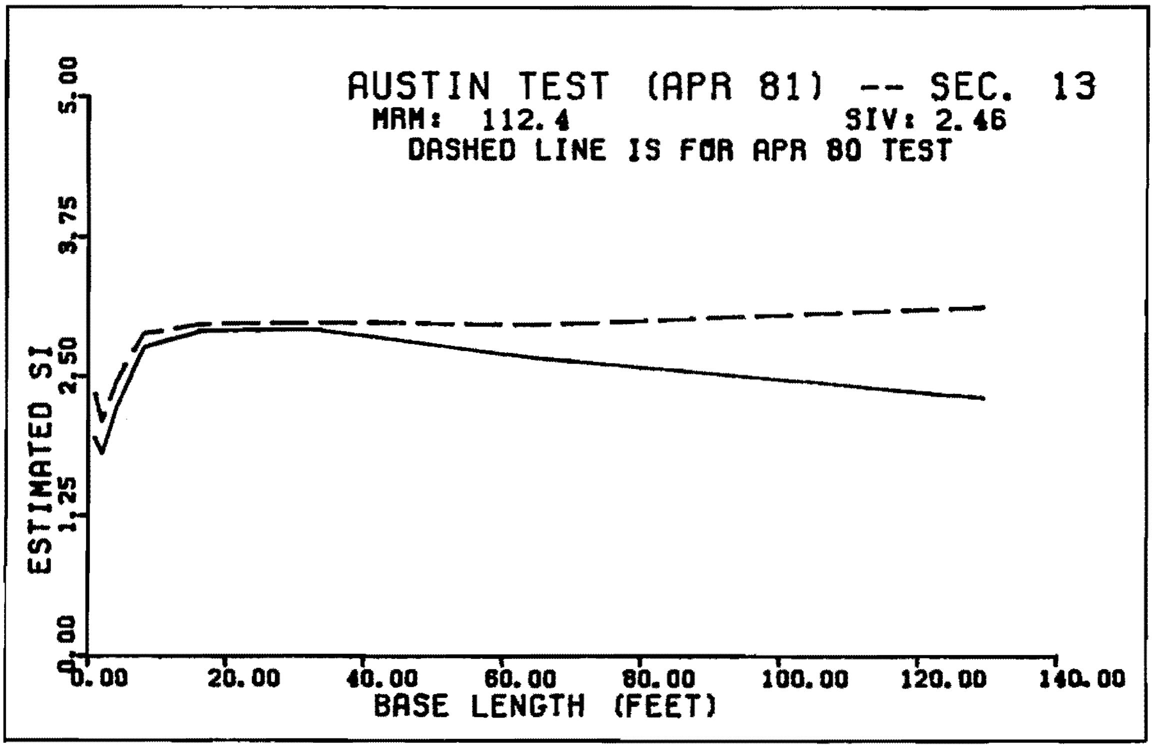
AUSTIN TEST (APR 81) -- SEC. 13
MRM: 112.4
SIV: 2.46
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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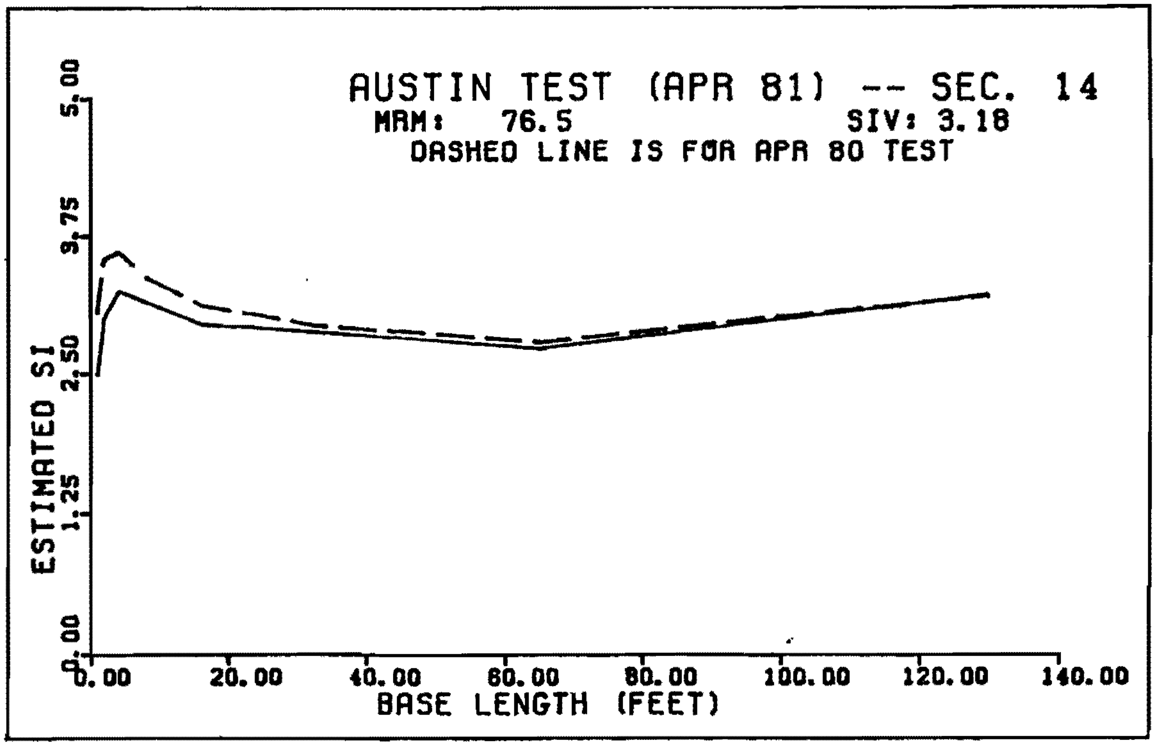
AUSTIN TEST (APR 81) -- SEC. 14
MRM: 76.5
SIV: 3.18
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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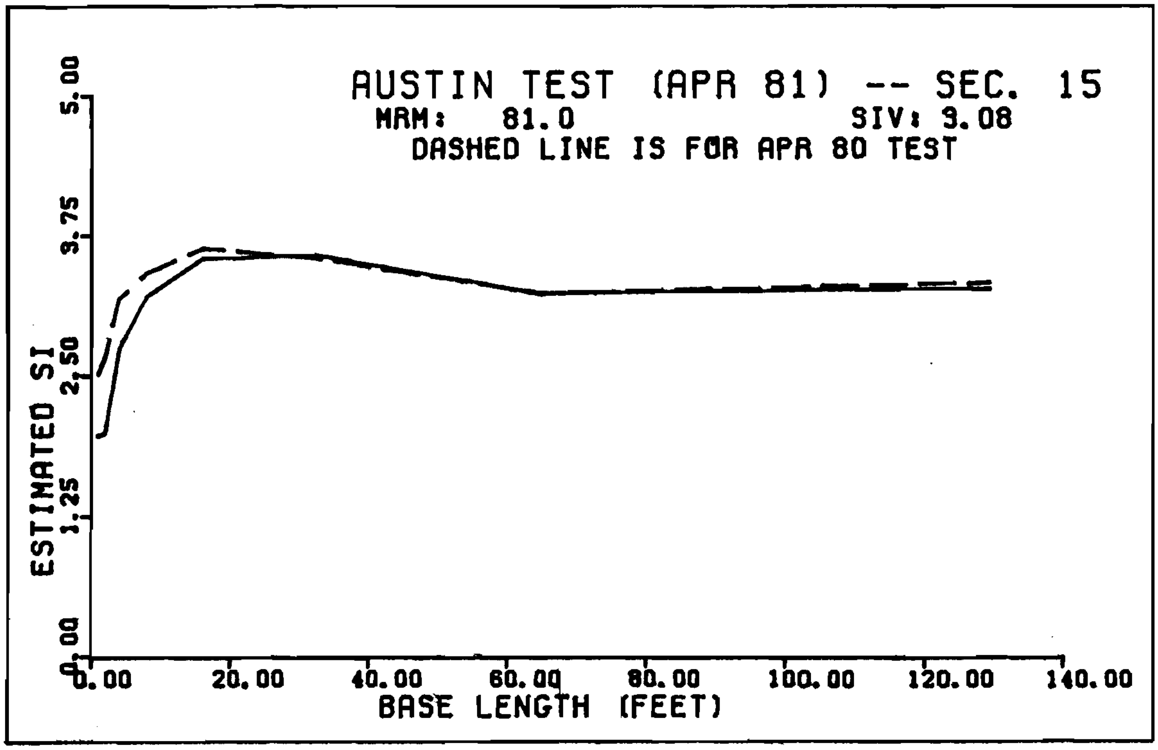
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 15
MRM: 81.0
SIV: 3.08
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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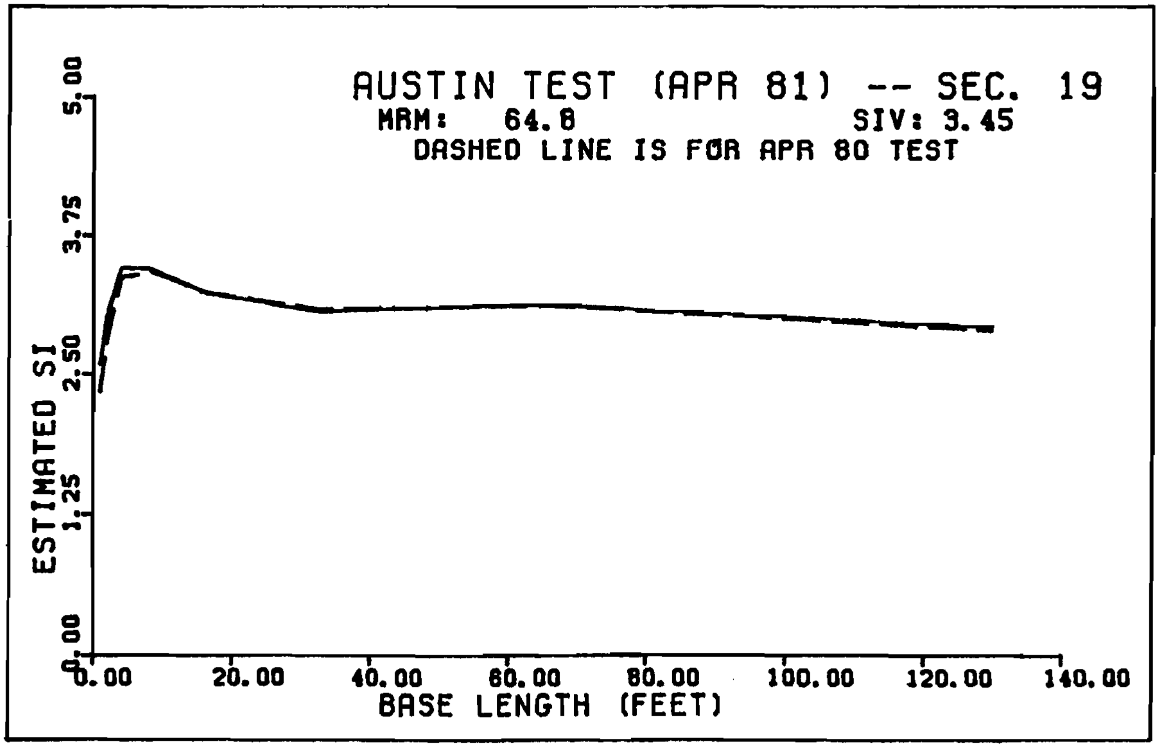
AUSTIN TEST (APR 81) -- SEC. 19
MRM: 64.8
SIV: 3.45
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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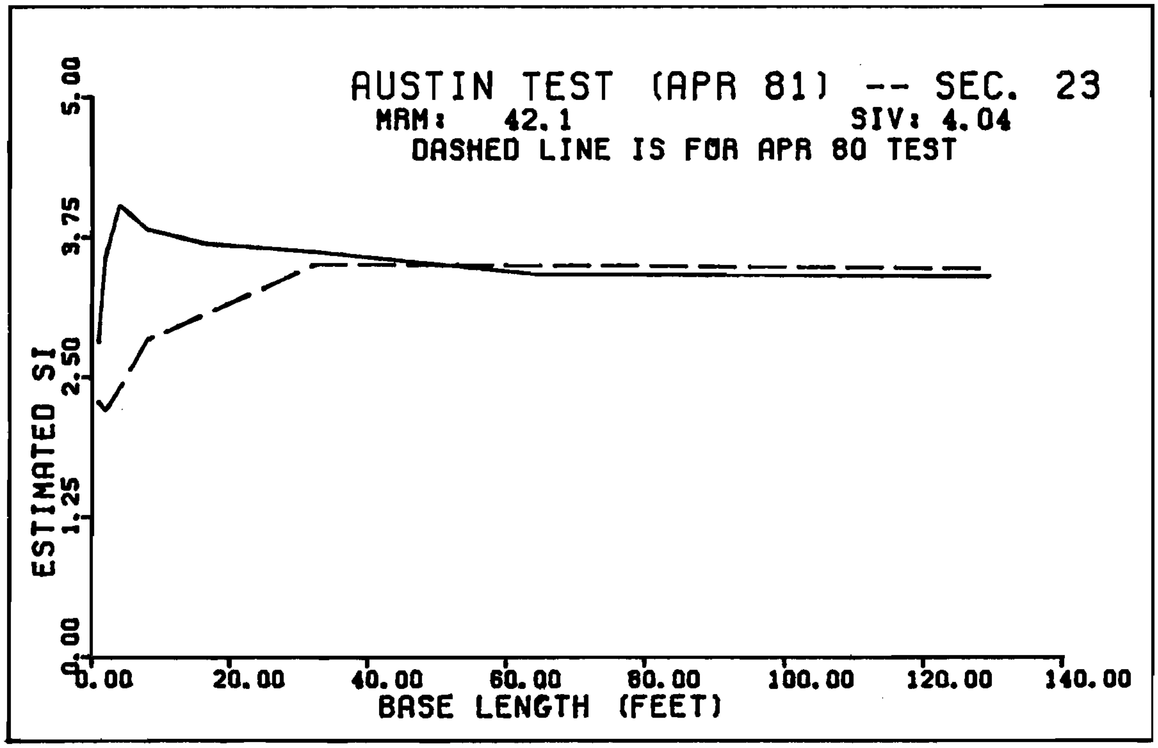
AUSTIN TEST (APR 81) -- SEC. 23
MRM: 42.1
SIV: 4.04
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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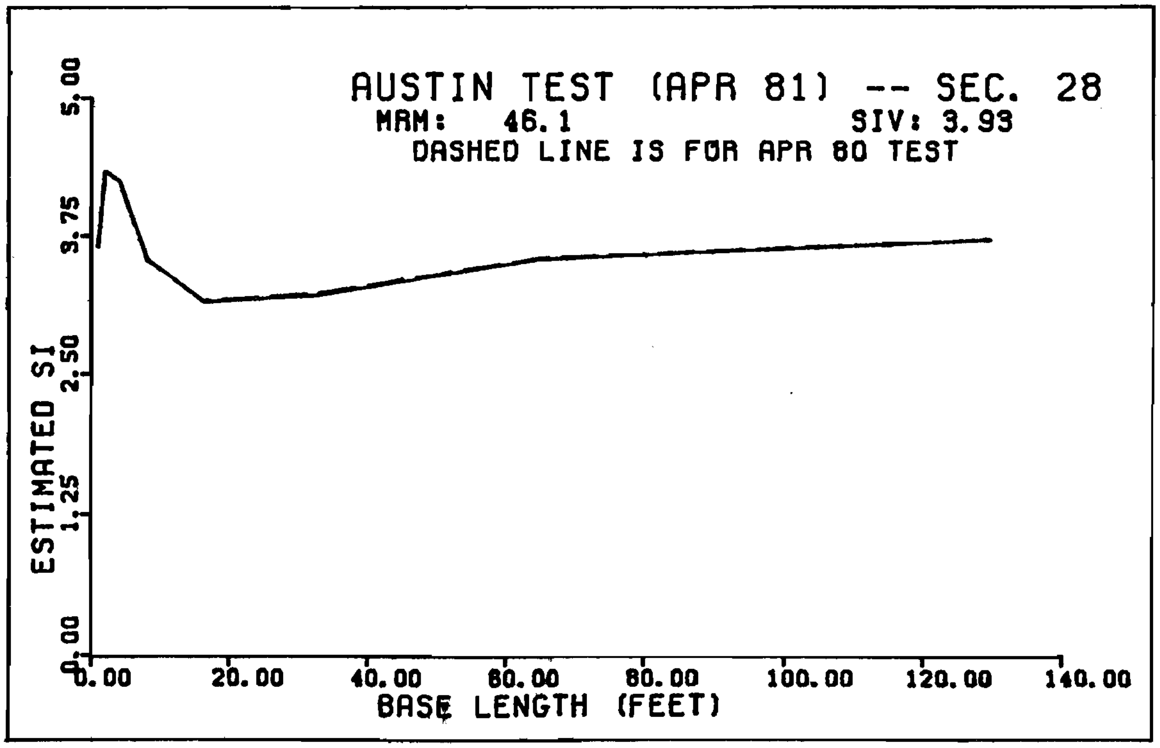
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 28
MRM: 46.1
SIV: 3.93
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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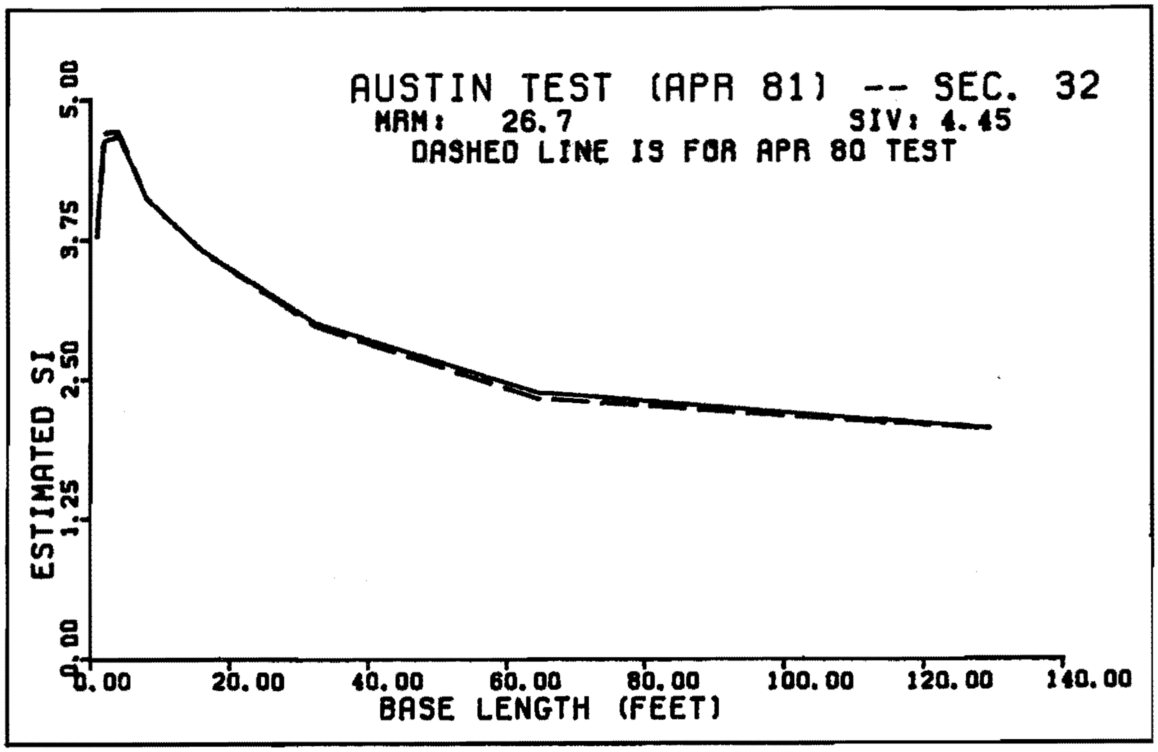
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 32
MRM: 26.7
SIV: 4.45
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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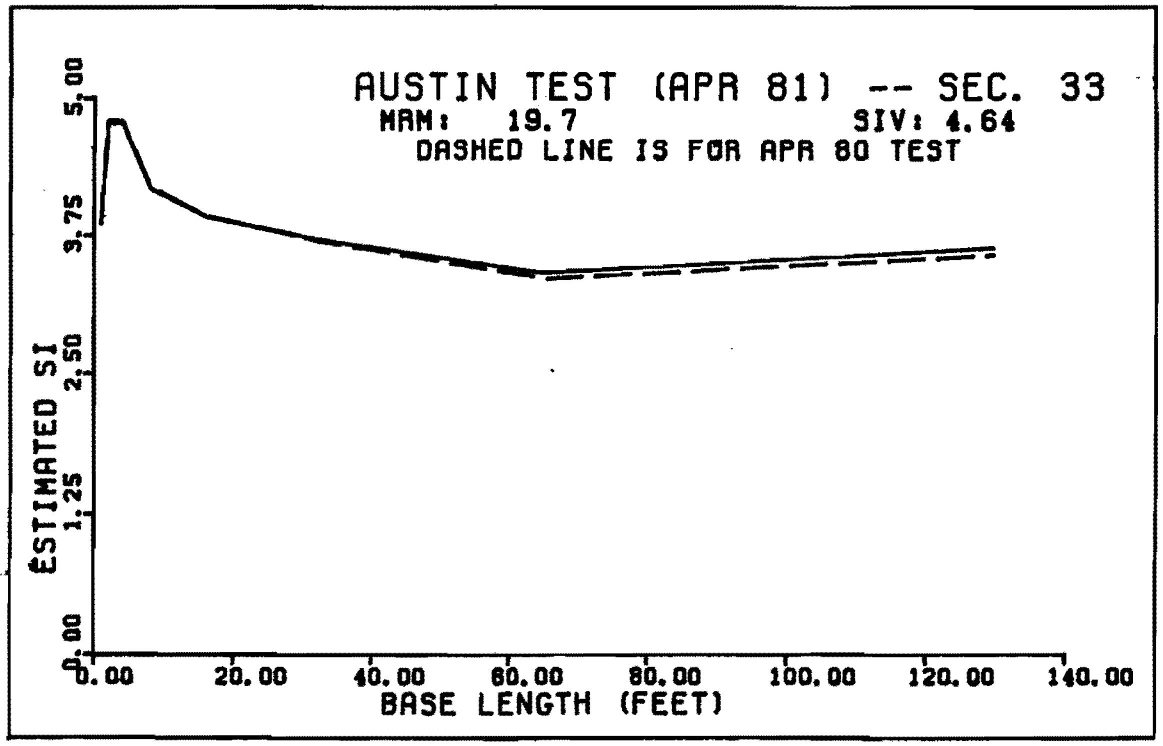
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 33
MRM: 19.7
SIV: 4.64
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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20.00
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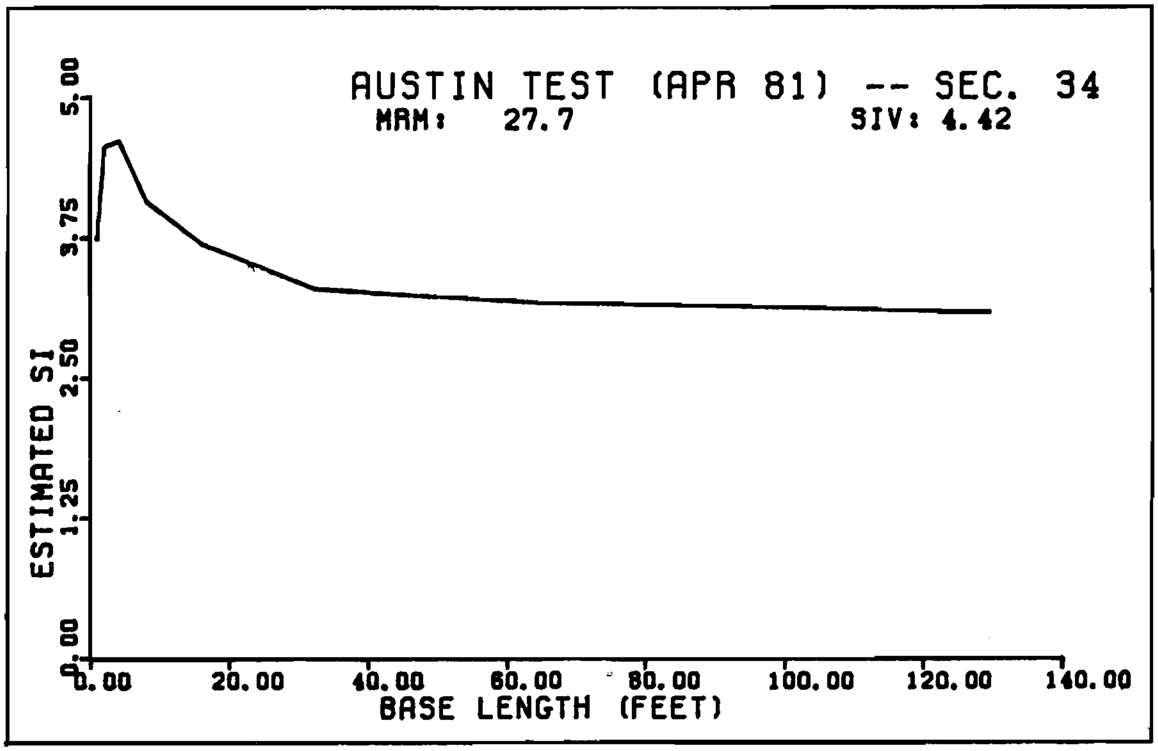
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 34
MRM: 27.7
SIV: 4.42
ESTIMATED SI
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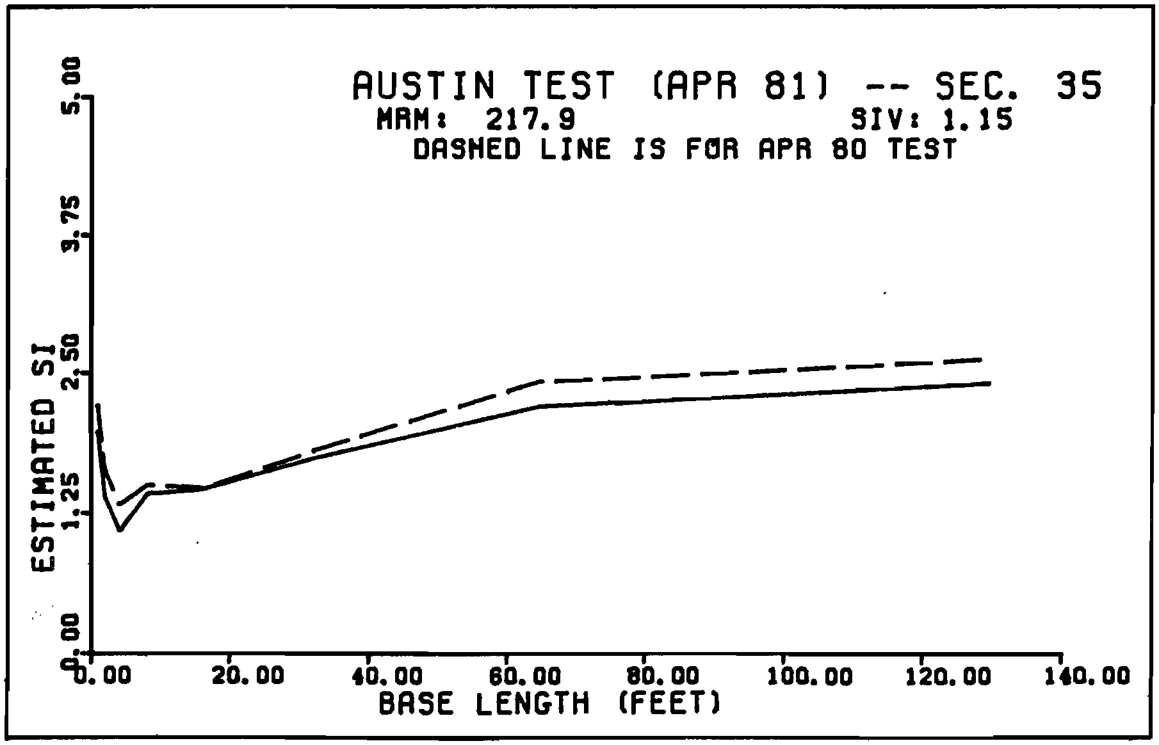
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 35
MRM: 217.9
SIV: 1.15
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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2.50
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5.00
0.00
20.00
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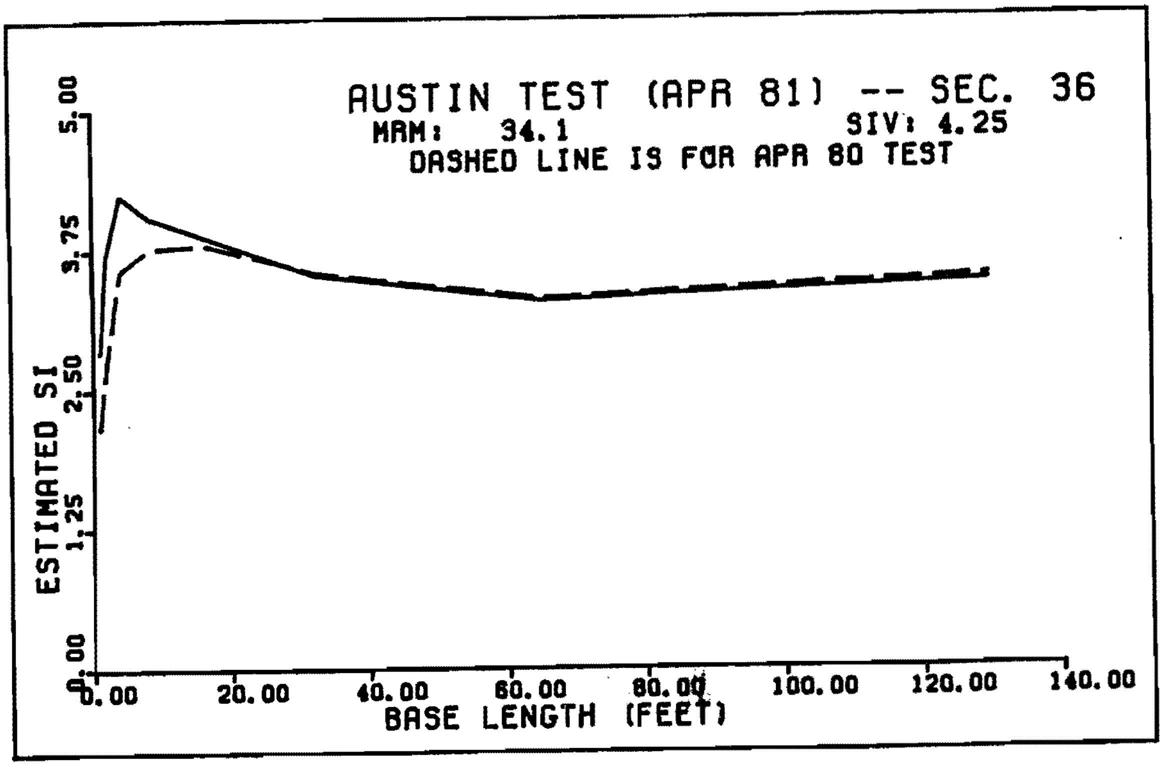
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 36
MRM: 34.1
SIV: 4.25
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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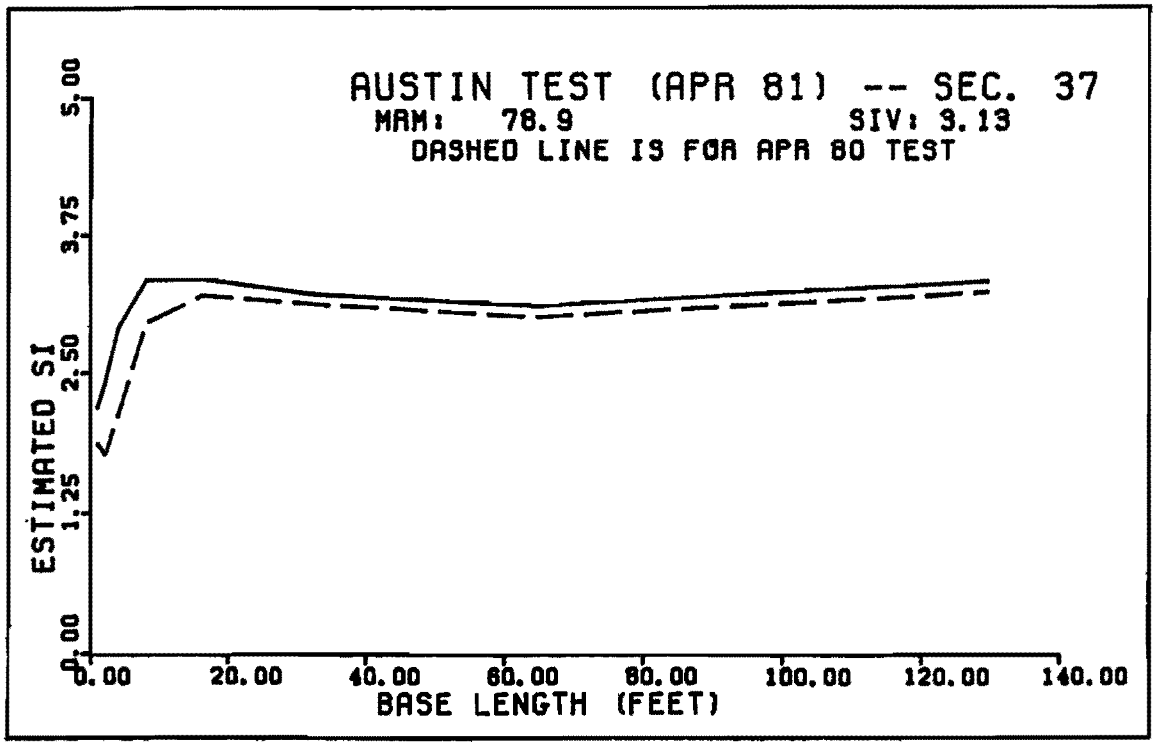
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 37
MRM: 78.9
SIV: 3.13
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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2.50
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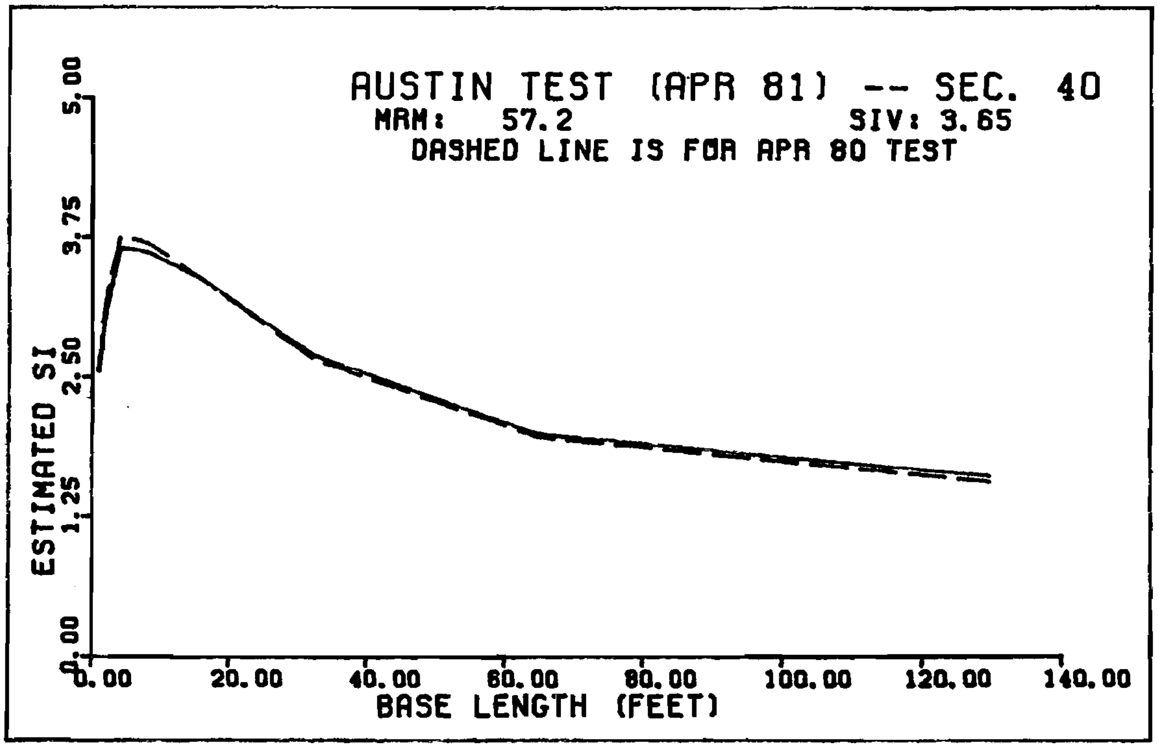
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 40
MRM: 57.2
SIV: 3.65
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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20.00
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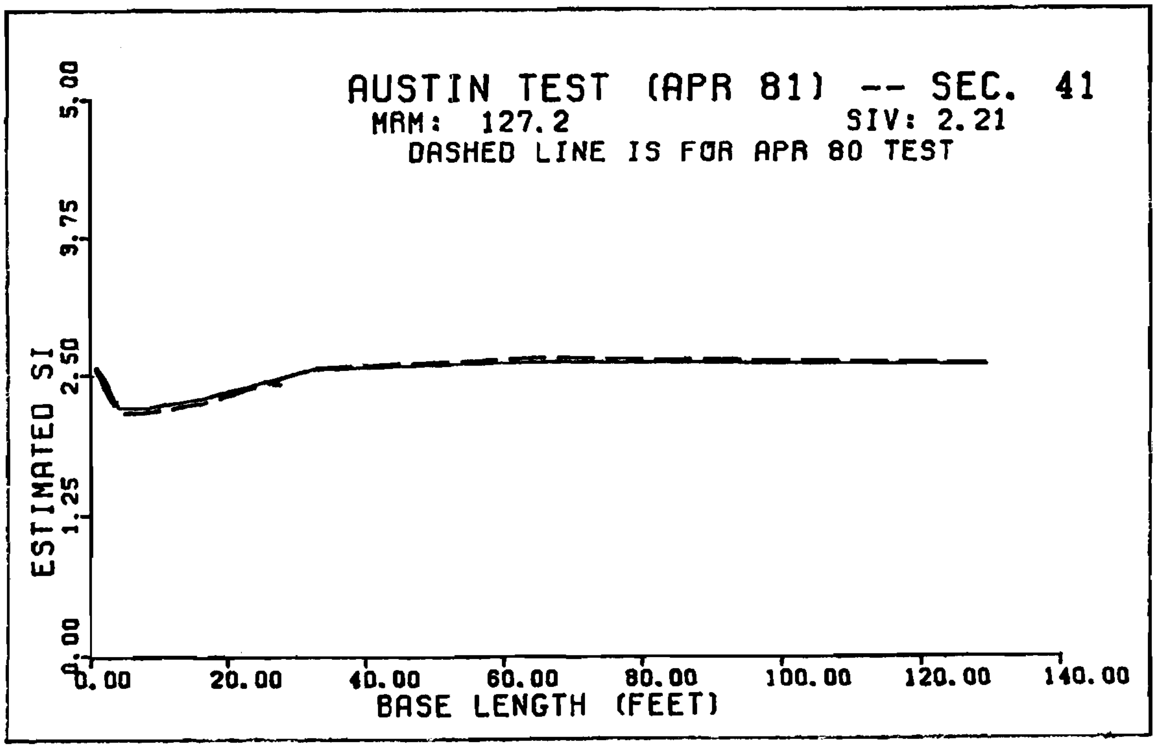
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 41
MRM: 127.2
SIV: 2.21
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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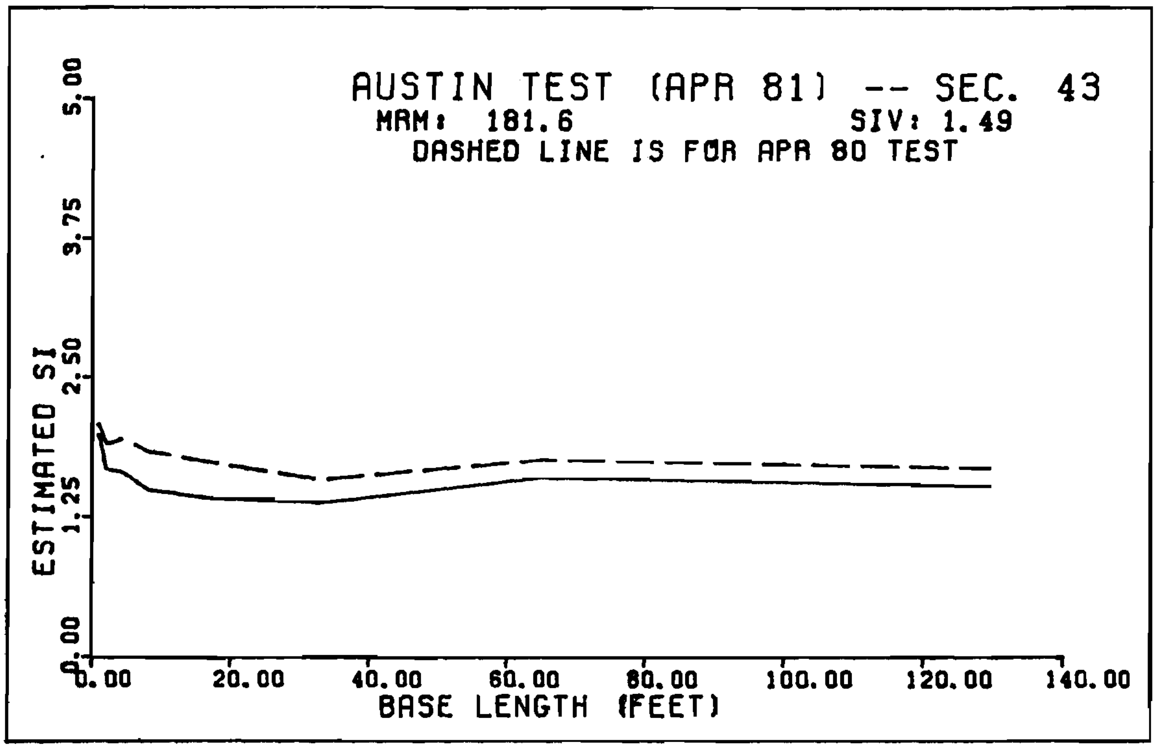
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 43
MRM: 181.6
SIV: 1.49
DASHED LINE IS FOR APR 80 TEST
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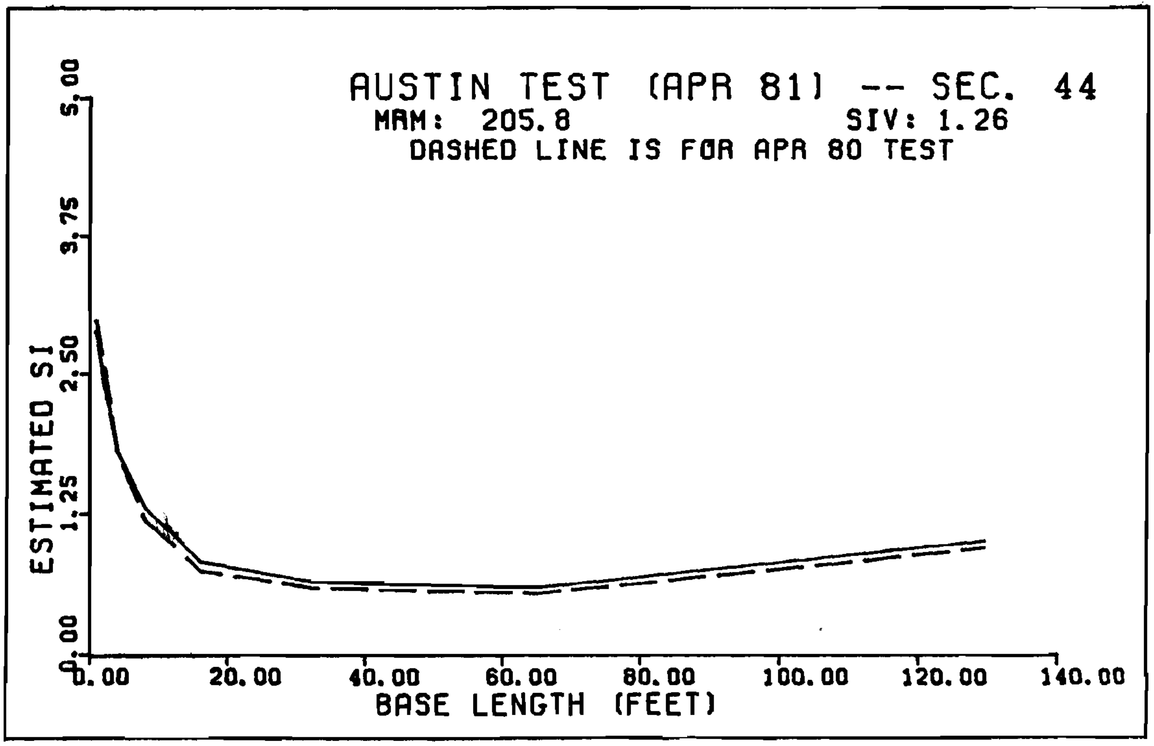
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 44
MRM: 205.8
SIV: 1.26
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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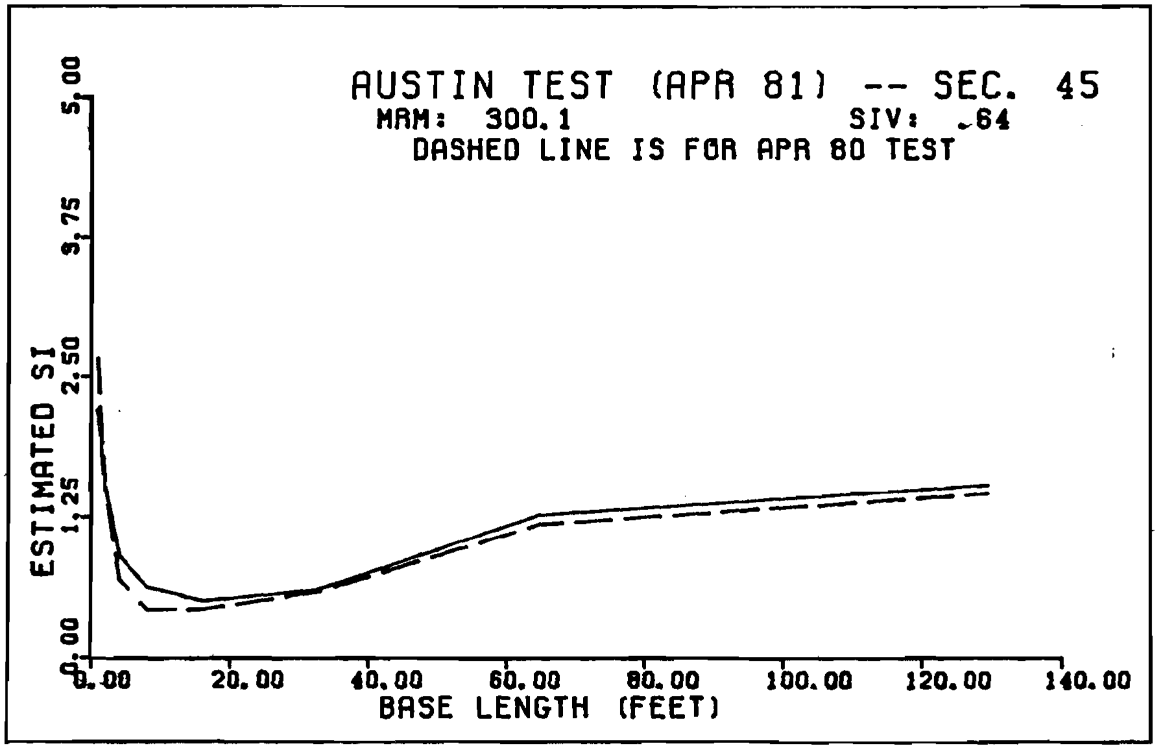
BASE LENGTH (FEET)


AUSTIN TEST (APR 81) -- SEC. 45
MRM: 300.1
SIV: .64
DASHED LINE IS FOR APR 80 TEST
ESTIMATED SI
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3.75
5.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
BASE LENGTH (FEET)

THE AUTHORS

David McKenzie joined the United States Air Force in November 1966 and served as Navigator and Electronic Warfare Officer in the Strategic Air Command. His current interests include cave exploration and surveying numerical linear algebra, and applied statistics. He is presently employed with The University of Texas at Austinas a Computer Programmer. Mr. McKenzie has served as chief programmer for the Pavement System Research Laboratory for the past three years. He has developed a number of Pavement Computer Programs and is thoroughly familiar with RPS, FRS, SAMP, SLAB and other basic programs.

W. Ronald Hudson is a Professor of Civil Engineering at The University of Texas at Austin. He has a wide variety of experience as a research engineer with the State Department of Highways and Public Transportation and the Center for Transportation Research at The University of Texas at Austin and was Assistant Chief of the Rigid Pavement Research Branch of the AASHO Road Test. He is the author of numerous publications and was the receipient of the ASCE J. James R. Croes Medal. He is presently concerned with research in the areas of (1) design of pavement management systems, (2) measurement of pavement roughness and performance, (3) rigid pavement slab analysis and design, and (4) low volume roads.

C. E. Lee is a Professor of Civil Engineering and Director of the Nasser Al-Rasid Transportation Engineering Laboratory. He served as Director of the Center for Highway Research for 17 years.

He specializes in several areas of transportation including weighing vehicles in motion and traffic simulation. He has been active in building the transportation engineering program at the University for the past 20 years and serves as advisor to numerous state and federal agencies, as well as to several industrial corporations.

Presently, he serves as faculty liaison with the International Road Federation and the Transportation Research Board.