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16. Abstract

This report describes a correlation study between an analog GM profilometer (the old profilometer) and a digital GM profilometer model 690D (the new profilometer). This correlation is very important because it provides the information necessary to make a smooth transition between the use of these two instruments. Multiple regression analysis is used to obtain Serviceability Index using root-mean-square vertical acceleration (RMSVA). RMSVA indexes are well defined and precisely measurable with the profilometer. A series of regression equations are presented in order to predict RMSVA from the old profilometer using the new profilometer.

This report also presents an evaluation of non-contact transducers in the profilometer, which makes possible an increase of the profilometer speed during the profiling process and decreases damage to the profilometer.

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by

German J. Claros
W. Ronald Hudson
Clyde E. Lee

Research Report Number 251-3F

Deployment of a Digital Road Profilometer
Research Report 3-8-79-251

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U. S. Department of Transportation
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by the

Center for Transportation Research
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The University of Texas at Austin

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

This report was completed at The University of Texas Center for Transportation Research, under Project 3-8-79-251, as a part of the Cooperative Research Program between The University of Texas and the Texas State Department of Highways and Public Transportation. One of the main objectives of the project is the deployment of the Digital Profilometer 690D. This report presents the correlation study between the old analog profilometer and the new digital profilometer. The incorporation of non-contact transducers to the profilometer is also presented.

The authors are particularly grateful to the entire staff of the Center for Transportation Research, who provided support throughout the analysis and preparation stages of this report. Special appreciation is due to Leon Snider and Joe Wise for their assistance with the testing program; Lyn Gabbert and Rachel Hinshaw for typing; and Bob Gloyd for his assistance in computational work. Gratitude is also expressed to many students who provided technical advice and assistance during the study, particularly Alberto Mendoza and Victor Torres.

German J. Claros
W. Ronald Hudson
Clyde E. Lee

LIST OF REPORTS

Report Number 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 RMSVA-derived Maysmeter simulation.

Report Number 251-2, "Development of a Computer Program (OVERLAY) to Simulate Laydown and Compaction of Asphalt Pavements," by S. Daniel Codas, W. Ronald Hudson, and Clyde E. Lee, presents the development of mathematical models to simulate laydown and compaction of asphalt pavements and the development of a computer program (OVERLAY) that incorporates these models.

Report Number 251-3F, "Performance of an Analog and a Digital Profilometer with Wheels and with Non-Contact Transducer," by German J. Claros, W. Ronald Hudson, and Clyde E. Lee, discusses the development of a set of regression equations in order to predict RMSVA from the old profilometer using the new model 690D profilometer. A set of equations is also presented in order to calculate the serviceability index (SIV) using the new profilometer. A study of the replacement of the tracking wheel with non-contact probes is presented herein with a summary of advantages and disadvantages of these devices in road profiling.

ABSTRACT

This report describes a correlation study between an analog GM profilometer (the old profilometer) and a digital GM profilometer model 690D (the new profilometer). This correlation is very important because it provides the information necessary to make a smooth transition between the use of these two instruments. Multiple regression analysis is used to obtain Serviceability Index using root-mean-square vertical acceleration (RMSVA). RMSVA indexes are well defined and precisely measurable with the profilometer. A series of regression equations are presented in order to predict RMSVA from the old profilometer using the new profilometer.

This report also presents an evaluation of non-contact transducers in the profilometer, which makes possible an increase of the profilometer speed during the profiling process and decreases damage to the profilometer.

KEYWORDS: Surface Dynamic Profilometer, road profile, root-mean-square vertical acceleration (RMSVA), Serviceability Index, non-contact transducers.

SUMMARY

In early 1967 an analog surface dynamics profilometer was introduced to the Texas SDHPT. After fifteen years a new digital model of the profilometer was purchased to replace the original analog profilometer. The purpose of this report is to present the correlation between these two instruments, which is very important in order to have a smooth transition of roughness records. The correlation study was based on simultaneous runs over pavement sections using both profilometers. Using step-wise regression techniques, two general regression equations were developed to predict Serviceability Index from the old profilometer, one equation for flexible pavements and the other for rigid pavements. A second set of regression equations was obtained to compare the root-mean-square vertical acceleration (RMSVA) values from the old profilometer for different base lengths with the new profilometer. These equations provide the basis for future studies involving the new profilometer.

The use of non-contact probes (transducers) to replace the tracking wheel in the profilometer was also studied. Three types of non-contact devices were used in this research (laser, infrared, and a high intensity light device). In general these devices have the same accuracy as tracking wheels in addition to the following advantages:

(1) The speed of the profilometer can be increased up to 50 mph,
(2) sections with high roughness levels can be profiled without damage to the profilometer, and
(3) high frequency vibration which is transmitted to the car frame by the trailing arm is eliminated, reducing possible hardware damage.

IMPLEMENTATION STATEMENT

Based on the findings of this study, it is recommended that the new set of regression equations to predict the serviceability index (SIV) be used. A new version of the computer program VERTAC which can be used to calculate RMSVA is presented for use by the SDHPT. The implementation of non-contact transducers in the profilometer is recommended, based on the advantages of these devices in the profiling operation. Some supplementary research will be necessary in order to choose the most convenient device.

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CHAPTER 1. INTRODUCTION

BACKGROUND

A primary concern among most highway agencies is the maintenance and upgrading of road surface quality. To accomplish this effectively requires an objective method of measuring the quality of road surfaces, which is a function of road roughness. The AASHO Road Test showed that about 85 percent of the road user's perception of road serviceability results from the roughness of its surface profile. Road roughness has been proven to be directly related to vehicle operating cost, riding quality, and safety. Furthermore, the measurement of road roughness can be used as an acceptable criterion for newly constructed or repaved roads.

Some departments already have an acceptance criteria for newly constructed or repaved roads. In such cases, roughness must not exceed a specified value as measured by a specified measurement method. Road roughness is defined as deviations of a traveled surface from a true planar surface that have characteristic dimensions that affect ride quality, vehicle dynamics, and pavement drainage. To quantify these characteristic dimensions it is necessary to know the dynamic behavior of the vehicle, vehicle speed, and the wavelength amplitude content of the road profile over which the vehicle travels.

There are presently several different road roughness measuring techniques in use worldwide. In general, roughness measuring systems can be classified into two types:

(1) Techniques which measure the actual road profile directly. An example of this type is the surface dynamics profilometer (Ref 1). Ideally this method gives accurate, scaled reproduction of the pavement profile. In practice, the range and resolution of any profiling device are limited, but within these limits the measurement may be called "absolute." The advantage of a profiling technique is that it records a great deal of information about the pavement profile that can be evaluated according to specific needs.

(2) Techniques which measure vehicle response to road roughness (roadmeters), such as the BPR roughometer, the Maysmeter, and the PCA meter. All roadmeters measure the dynamic effect of the roughness, but this type of measurement does not define the profile of the pavement. Some wavelengths are amplified and other are attenuated; thus, the selection of the mechanical system is critical.

The first Surface Dynamics Profilometer (SDP) was introduced into the SDHPT in early 1967. The original profilometer hardware recorded all profile data in analog form. Consequently, a laboratory-based analog-to-digital conversion of the measurements was required before profile summary statistics could be computed. This equipment was replaced with a new model, the 690 Digital SD profilometer, in early 1982. A discussion of the implementation of this new profilometer and its correlation with the old model are presented herein.

Objectives of the Study

The main purpose of this research project was to assist the SDHPT in purchasing the 690D SD Profilometer and to help effect a smooth transition in use of the new equipment. The basic objectives of the research project have been to:

(1) assist the SDHPT in preparing specifications for the purchase of a 690D SD Profilometer,

(2) continue maintenance and operation of the old profilometer until one year after delivery of the new profilometer,

(3) adapt the on-board computer software of the model 690D to the needs of the SDHPT,

(4) continue providing road surface measurements as required by the SDHPT, and

(5) make the necessary procedural changes for using to full advantage the new or improved features of this new model, in addition to transferring existing profilometer functions to the model 690D.

The main objective of this report, then, is to present a correlation between the analog profilometer (the old profilometer) and the 690SD all digital profilometer (the new profilometer) which is being used by the SDHPT. A second objective of this report is to evaluate the use of non-contact transducers on the profilometer, which will make it possible to increase the profilometer speed during the profiling process.

Scope

This report includes (a) road processing techniques and the advanced features of the digital profilometer (Chapter 2), (b) a correlation between the analog profilometer and the digital profilometer (Chapter 3), (c) the use of non-contact transducers in road profiling as a modification of the standard profilometer (Chapter 4), (d) a summary of the results of the study (Chapter 5), (e) conclusions drawn from the study results (Chapter 5), and finally (f) recommendations for improvements and further work on this area of study.

CHAPTER 2. ROAD PROFILE DATA PROCESSING TECHNIQUES AND FEATURES OF A DIGITAL PROFILOMETER

BACKGROUND

Many methods have been developed for processing road data profile, but there is no standard or most-commonly-used method. The available methods can be classified into three groups: (1) wave analysis techniques, (2) theoretical roadmeter simulation methods, and (3) indirect roadmeter simulation method.

A measured profile contains pavement roughness information which can be evaluated to satisfy several different needs. For example, researchers conducting roughness studies may want detailed information from the measured profiles, e.g., a full series of waves with average wavelengths and their respective amplitudes. Highway engineers, on the other hand, may want only to rank roads according to their riding qualities using a single roughness number, e.g., quarter-car index. To suggest a single data processing technique as a standard technique may not serve any useful purpose. The technique used will depend on the roughness information required . However, it must be kept in mind by highway engineers that some data analysis methods are better than others with respect to certain applications.

WAVE ANALYSIS METHODS

This group of processing techniques treats a measured profile as a complex wave, thus applying mathematical analysis to separate the complex wave into a set of simple waves and amplitudes. A weighting function can be determined through correlation. This weighting function is used to assign the relative contribution of the separated simple waves. The wave analysis methods include the following techniques.

Harmonic Analysis

The basic assumption of wave analysis is that a measured profile is a periodic wave. Harmonic analysis then breaks down a profile record into a harmonic series of sinusoidal waves. Figure 2.1 shows a typical harmonic series derived by plotting the roughness amplitudes as a function of wavelengths. Different roads will have different combinations of amplitudes and wavelengths. Therefore, the extent of this roughness can be used to evaluate its potential effect on road riding quality (Ref 1).

Power Spectral Density

Power spectral density is a method which researchers use to analyze a measured profile (Refs 2 and 3). The method treats a measured profile as a random signal. The fast-fourier transform is used to represent a measured profile and it can be processed to find roughness amplitudes and spectral density estimates for a set of wave bands. Walker and Hudson (Ref 2) developed a present serviceability index model using 22 terms for spectral density estimates. They also wrote a computer program, called SI2, for analyzing digital profile data. The Texas State Department of Highways and Public Transportation (SDHPT) for some time has used this method to process the SD Profilometer data in order to obtain present serviceability indices for selected calibration test sections. The power spectral density analysis was more recently replaced by another data analysis method, developed by McKenzie et al (Ref 4).

Digital Filtering Technique

A digital filtering process was used by Williamson (Ref 5) to separate a measured profile by wavelengths. He also developed a computer program, called ROKYRD, which does all computation for a complete road roughness analysis. This program provides a table of roughness values, which includes the serviceability index based on roughness amplitudes of 4 to 10, 10 to 25, 25 to 50, and 50 to 100-foot wavelength bands. The SI calculation is based

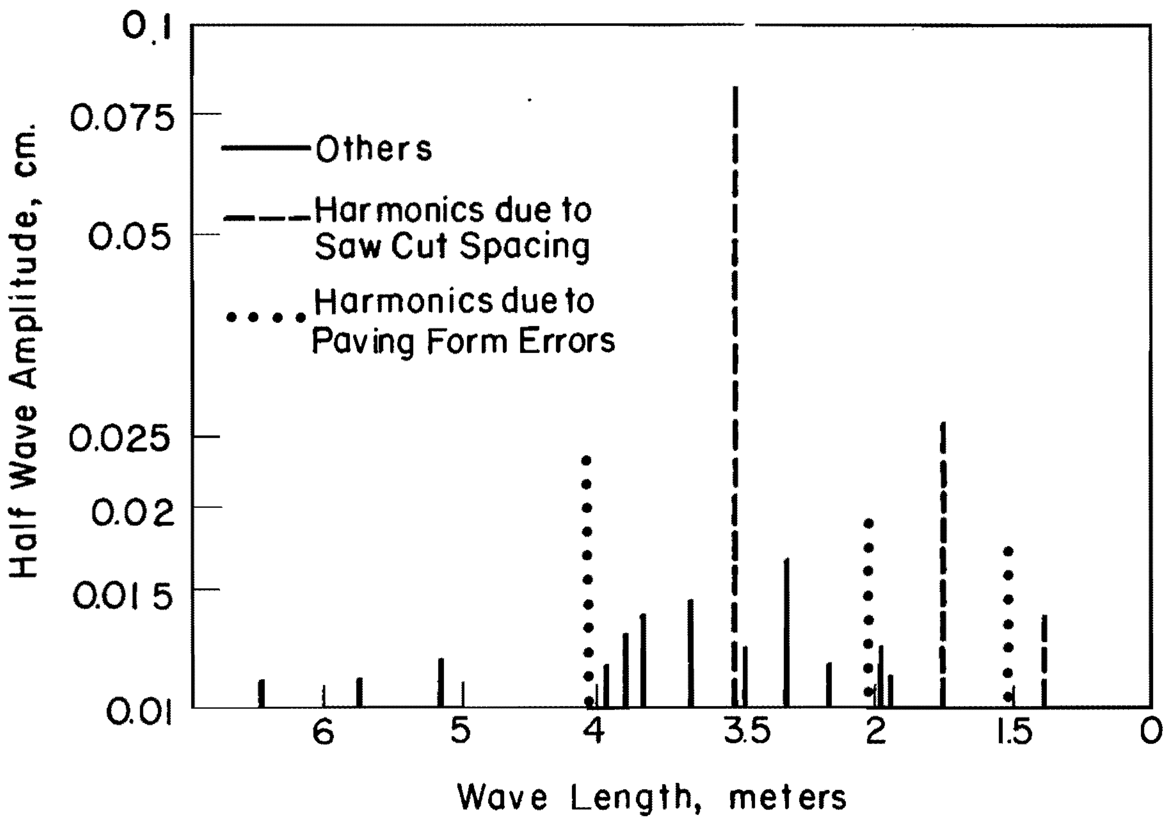

Fig 2.1. Harmonic analysis of a road.

on the models which use the 50th and 90th percentile amplitudes of longitudinal and transverse waves.

THEORETICAL ROADMETER SIMULATION METHOD

In this method, computer programs are used to simulate the dynamic response of a vehicle to a measured profile using a set of differential equations to model the vehicle behavior. The characteristic parameters, such as masses, spring constants, and damping coefficients, are selected so as to be representative of a real vehicle. This method, which is time stable, provides roughness response of a vehicle or roadmeter to a measured profile. The simulation program can be built to match any desired dynamic model. It provides an estimate of the roughness response of a roughometer without actually running the roughometer over a measured profile.

The direct simulation approach has become more and more popular among highway authorities. The method offers practical roughness index statistics from the measured profile. K. J. Law, Inc., the manufacturer of the 690D profilometer, has developed several simulation programs for the SD profilometers. Some of these programs are the Maysmeter Index (MMI), the BPR roughness index, and the PCA roughness index. Gillespie (Ref 6) recommended in an NCHRP project report that all response-type systems be calibrated by correlating their output against the roughness measurements obtained from a profilometer in conjunction with a simulation of a selected reference response type system, on a number of roads. In the same project a Maysmeter simulation model which was developed was suggested as a standard roughness index.

A program called QCSIM (Quarter-Car Simulation) was developed at The University of Texas at Austin. This is a digital version of the Brazilian profilometer quarter-car simulator (Ref 7). The researchers of a highway cost study used a standard roughness value called Quarter-Car Index (QI) in order to calibrate a set of Maysmeters.

The algorithm of the QCSIM program uses a transition matrix technique to solve a set of differential equations, for which constants are defined by field measurements of the BPR roughometer characteristics. More information on the program and its listing is included in Ref 8.

QCSIM was verified through a direct comparison between the digital quarter-car index (QI_{UT}) and the analog quarter-car index (QI_{BRA}) on 17 Brazilian test sections. Figure 2.2 illustrates that comparison, which indicates good agreement except for a few outlier points. Hence, QCSIM is a data processing technique for analyzing a measured profile.

INDIRECT ROAD METER SIMULATION METHOD

The indirect simulation method does not attempt to model the response of a vehicle to the road profile, as the theoretical simulation methods do, but rather attempts to develop a regression model which predicts a single-valued roughness index. This method uses a simple and physically meaningful function of a measured profile as the summary statistic. Some of the processing techniques which can be classified with this method are slope variance (SV), root-mean-square vertical acceleration (RMSVA), and mean absolute vertical acceleration (MAVA).

The Root-Mean-Square Vertical Acceleration Technique

This method was developed by McKenzie et al (Ref 4) in an attempt to improve the Texas Maysmeter calibration procedure. The method is based on an analysis of the vertical accelerations (VA) of a point moving along a measured road profile at a selected speed. This technique uses a relatively simple summary statistic; therefore, the results are not critically sensitive to profile measuring technique and resolution. The composite measure of a profile can be simply described as the root-mean-square difference in the slopes between adjacent points on the profile, where each slope is the ratio of elevation change to distance over a series of fixed distance increments. This method was named the root-mean-square vertical acceleration (RMSVA) for two reasons.

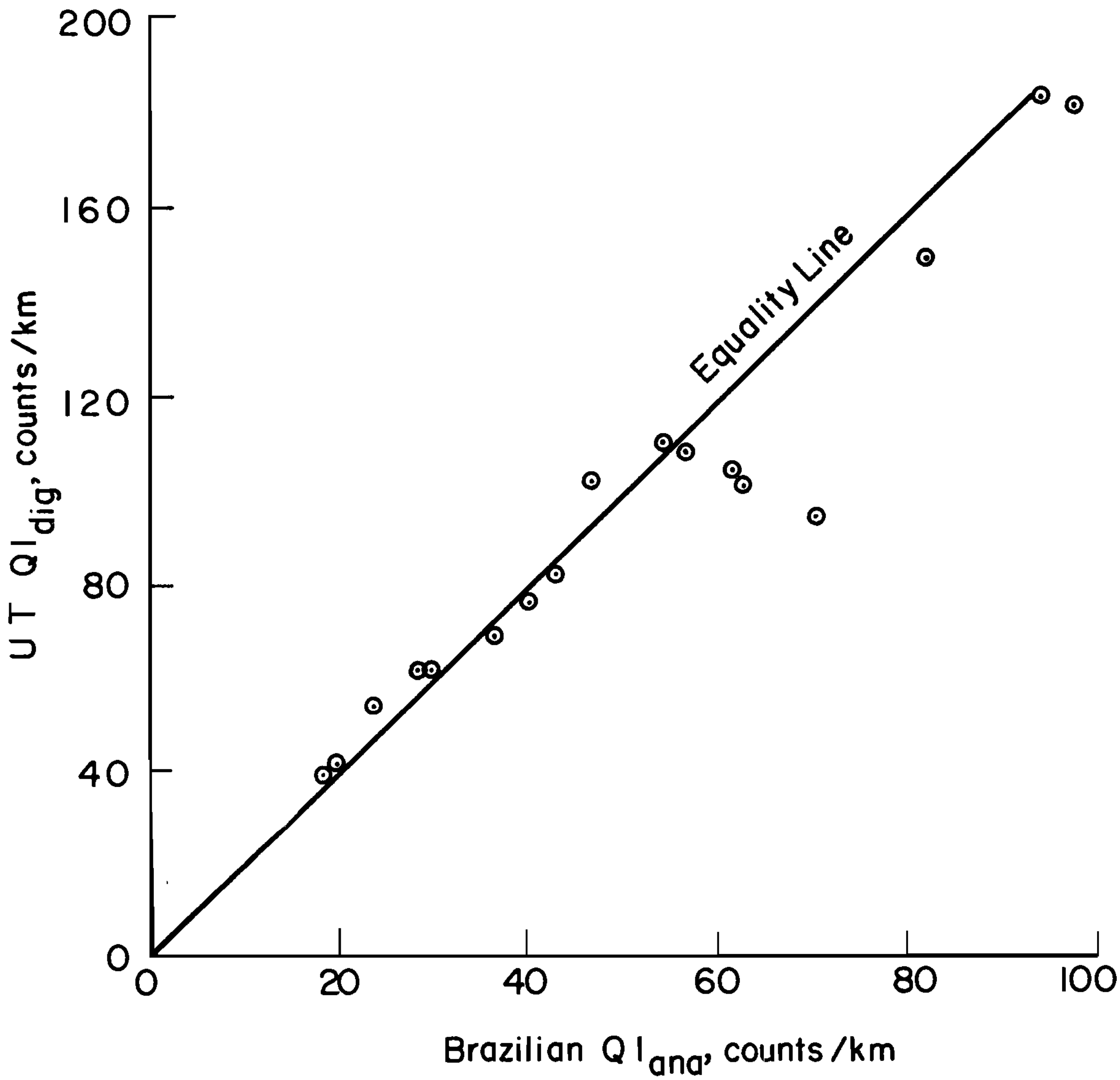

Fig 2.2. Quarter Car Index obtained from UT QCSIM vs. Quarter Car Index obtained from the Brazilian analog Quarter Car simulator.

First, the computation of vertical acceleration is equivalent to the second derivative of the vertical displacement of a wheel moving at a constant horizontal speed with respect to the time taken to accomplish the vertical displacement between discrete elevation points. Second, the root-mean-square of a series of vertical acceleration values can be computed. RMSVA is defined more exactly as follows.

Consider that Y_1, Y_2, ... Y_N represent elevations of equally spaced points along one wheel path. If s is the horizontal distance between adjacent points (the sampling interval), then a simple estimate of the second derivative of Y at point i (see Fig 2.3) with respect to distance is

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

$$= \left(Y_{i+k} - 2Y_i - Y_{i-k}\right) / (ks)^2 \qquad (2.1)$$

where

$(S_b)_i$ = second derivative of Y at point i with respect to the base length distance b,

b = base length.

And

$$b = ks \qquad (2.2)$$

where

k = an arbitrary integer used to define b (base length) as a multiple of s (sampling interval), and

s = sampling interval, i.e., the horizontal distance between adjacent elevation points at which the profile data were taken.

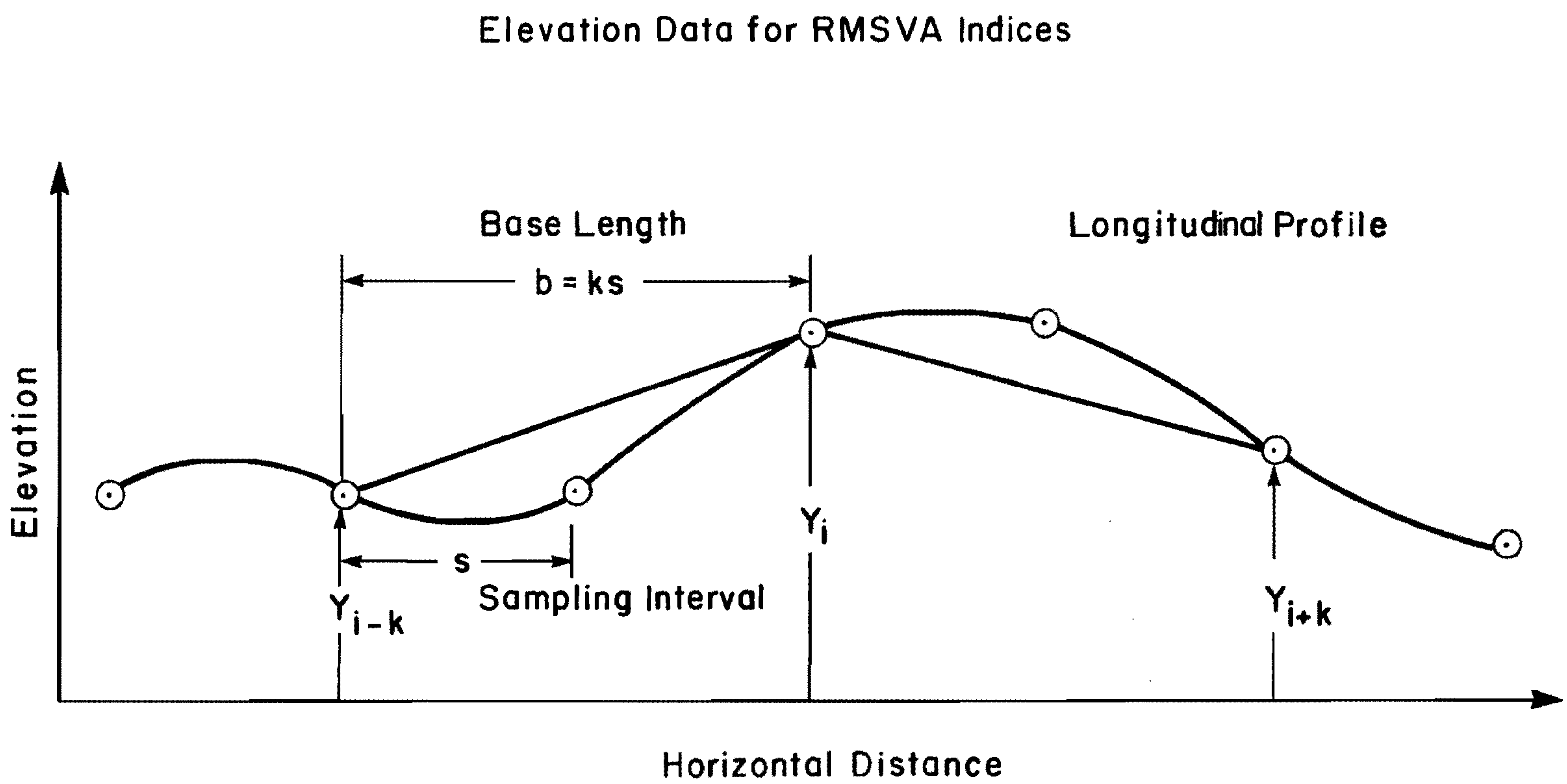

Fig 2.3. Basic terminology using the RMSVA method.

Root-Mean-Square Vertical Acceleration (RMSVA)

(RMSVA) at Base Length (b) is Proportional to the Root Mean Square Difference Between Adjacent Slopes Connecting Points that are b Distance Apart.

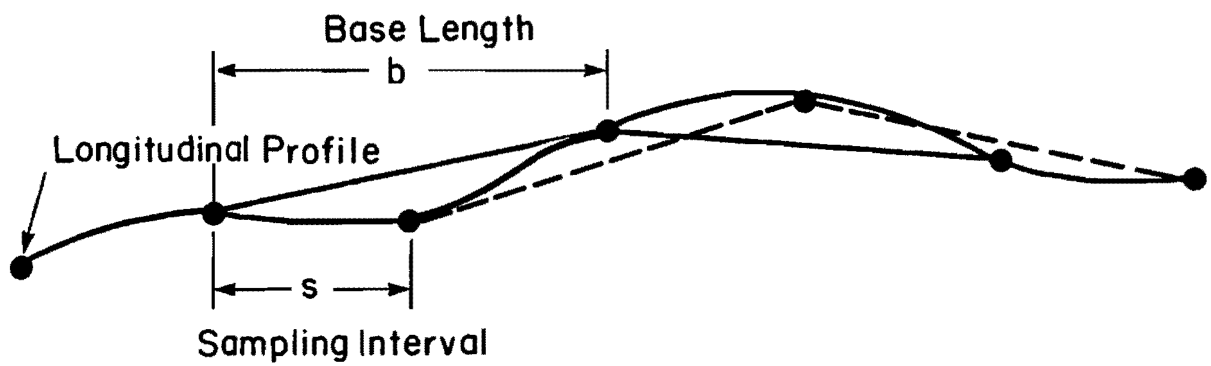

Fig 2.4. Graphical illustration of the RMSVA concept.

The root-mean-square vertical acceleration corresponding to the base length VA_b (see Fig 2.4) is

$$VA_b = C \left[\sum_{i=k+1}^{N-k} (S_b)_i^2 / (N - 2k) \right]^{1/2} \quad (2.3)$$

where

VA_b = root-mean-square vertical acceleration corresponding to the base length b,

N = total number of elevation points, and

C = a constant required for unit conversion from a spatial acceleration for a frequency domain acceleration.

In this study, $C = 5378\ ft^2/sec^2$, assuming profile dimensions are in feet and the hypothetical objective is travelling at a speed of 50 mph.

It can be observed that specifying the base length, b, is essential if RMSVA is to be a meaningful description of the road profile. VA_b will tend to increase dramatically as b is decreased. Furthermore, VA_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, b. The base length should be extremely small in order for this numerical solution to match the closed form solution for the vertical acceleration of a point. However, it is not so important to find the exact value of that second derivative of the road profile, because it is the roughness index which is ultimately related to the road roughness. The sensitivity of RMSVA to base length renders it a valuable statistic for describing the roughness contained in a road profile. Therefore, RMSVA should not be used as a single roughness index but rather as a set of indices, say VA_i, i = 0.5, 1, 2, ..., which collectively can reveal many of the pavement characteristics which are usually associated with the riding quality of a road.

Conclusions About Profile Data Processing Techniques

The previous section briefly describes methods which have been developed for processing data points from a measured profile. Some of the methods, such as the wave analysis, are mathematically involved. The physical meanings of their outputs are not easy to understand, but they provide very detailed information about the shape of the measured profile. The techniques based on modelling the response of a mechanical system to the profile (the roadmeter simulation techniques) use many assumptions and simplifications in order to accomplish such a simulation. As a result, the artificial or simulated results are not always exactly the same as the real ones. Thus, simulators such as QCS, QCSIM, and MMI should be looked at as tools to predict the relative response of a real roadmeter type instrument. Simulators can help to understand the interaction between road profile and the vehicle. The sensitivity of a roughness measuring device to dynamic characteristics (e.g., spring constant, damping coefficient, masses, wind and tire pressure) is very important.

In the present study RMSVA was selected to characterize the road surface. This method has been successfully used by the SDHPT in recent years as a basis for estimating serviceability index and for calibrating Maysmeters. The great advantage of this method is that it provides a means for producing RMSVA statistics from a road profile that can be associated with various wavelengths.

Description and Advanced Features of the Digital Profilometer

The Model 690D Surface Dynamics Profilometer is a system which measures the vertical motion of a van-type vehicle and the attached profiling wheels as the vehicle travels over a pavement section. These measurements are used to obtain an estimate of the road profile. The operating principle of the device is described in Ref 1. The components of the device are

(1) profilometer vehicle,
(2) tracking wheels with potentiometers,
(3) accelerometers,

(4) digital distance recorder,
(5) profile computer,
(6) magnetic tape recorder,
(7) strip chart recorder,
(8) roughness index and quarter-car simulator (optional), and
(9) operator's console.

The profilometer system contains suitable transducers, both for measuring road surface profile and for obtaining associated data, such as distance traveled, and vehicle speed. The transducers for measuring the road surface profile consist of a linear-displacement sensor (potentiometer) and an accelerometer for each wheel track. The linear-displacement sensor produces an electrical signal which is proportional to the relative displacement of the road with respect to a point on the frame of the profilometer vehicle. The accelerometer senses the vertical acceleration of this same point on the vehicle frame and thus provides the basis for computing its vertical displacement through double integration. Both the linear displacement sensor and the accelerometer signals are inputs to the digital profile computation. Distance and speed information about the longitudinal movement of the vehicle is obtained from the digital distance recorder. The digital profile signal is processed in real time by a computer located in the vehicle as the vehicle is driven along the road. The digital computer has sufficient computation power to perform road profile computations at one-inch intervals in both wheel paths and to calculate optional roughness indices simultaneously with the vehicle travelling at speeds up to 22 mph. Figure 2.5 shows all the systems in the profilometer.

The principal operational advantages of the new digital profilometer as compared with the old profilometer are given below.

(1) Almost limitless range in elevation can be handled by digital integration of electrical signals.
(2) Selectable digital wavelength filtering is incorporated into the new equipment. The profile cutoff frequency set by the operator remains fixed as the filtering system adjusts automatically to the

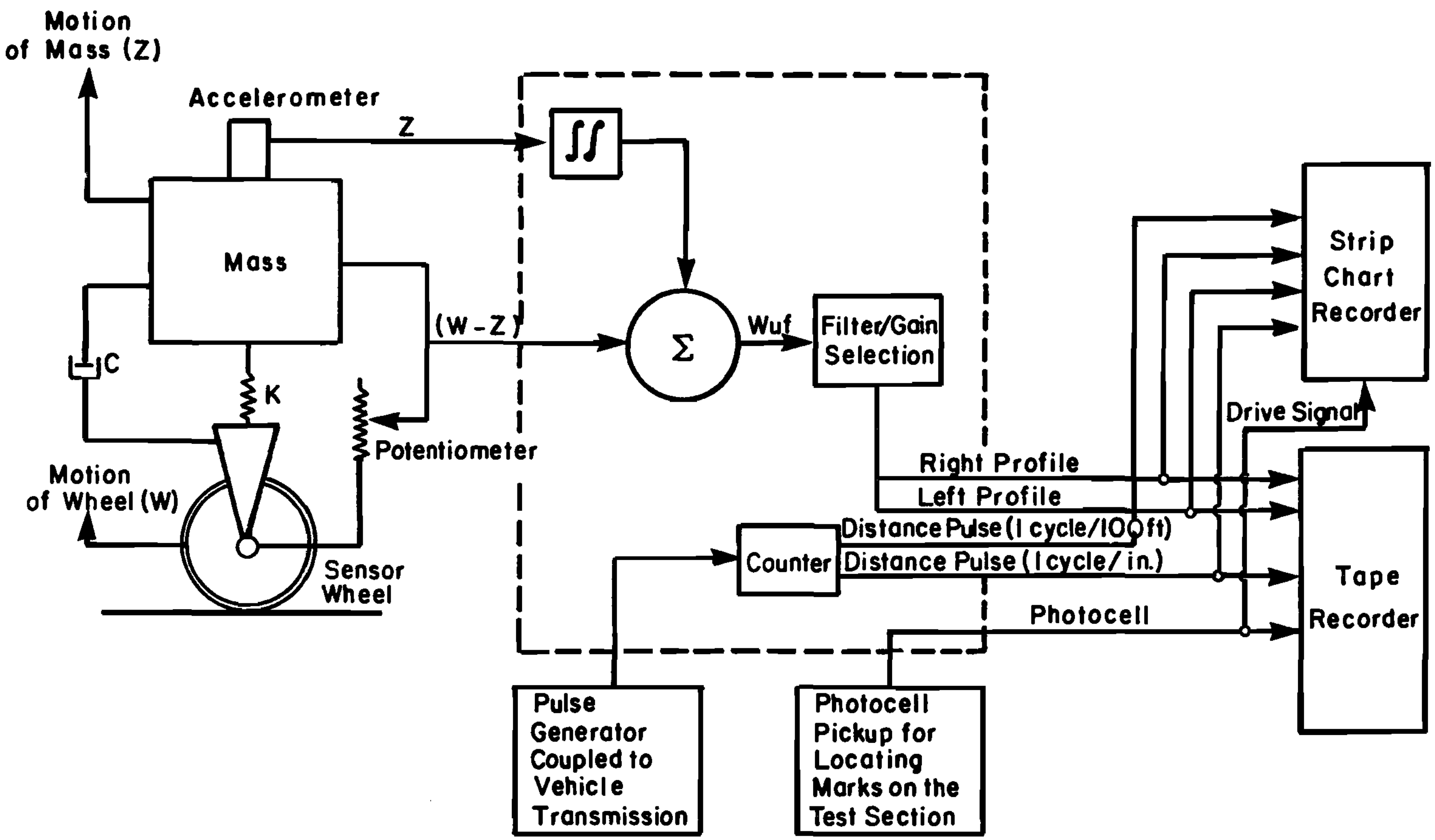

Fig 2.5. Block diagram of surface dynamics profilometer measurement system (after Ref 1).

speed of the vehicle. The maximum recommended wavelengths are 300 feet at 10 mph, 1,000 feet at 34 mph, and 1,600 feet at 55 mph. The wavelength selection is not a function of vehicle speed and does not change as vehicle speed is changed; however, the maximum measurable wavelength is a function of vehicle speed, as stated before.

(3) A two-channel strip chart recorder provides an instantaneous and permanent record of the road profile. One channel displays the right wheel path profile and the other channel displays the left wheel profile. The operator may specify any desired chart scale factor as inches of road profile per major chart division independently for the left and right profiles. However, the digital magnetic tape-recorded real data are independent of such scale factors and are recorded at full resolution.

(4) Calculation of various roughness statistics (e.g., quarter-car index, RMSVA, etc.) can be accomplished on board the vehicle. The main data processor can be reprogrammed, and new programs can be added.

(5) A magnetic tape recorder is provided. Compatible nine-track digital magnetic tape recorder with dual 800 bit per inch (BPI) non-return to zero (NRZ) and 1,600 BPI phase encoder (PE) recording capability is used to record road profile data. The format for each profile point is a 24-bit binary number. This allows a resolution of 0.001 inch and a range of $\pm$ 8388.6 inches. The data are organized in a file structured format so that each run is contained in one file.

(6) An electric typewriter input-output console for printing these statistics and for recording other information about a particular profile is provided.

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

(8) A van larger and more functional than the old model houses the equipment.

Typical Application of the Profilometer

A brief summary of current or recent SDHPT activities in which the 690SD profilometer is used is given here:

(1) Maysmeter Calibrations. The SD profilometer has provided, on a regular quarterly basis, estimates of the serviceability index measurements for approximately 30 Austin test sections, which are used as calibration sections. Maysmeters are calibrated by running them on the test sections, and then scaling their measurements to fit the most current profilometer data. Report 251-1 gives a standard procedure for Maysmeter calibration based on profile statistics.

(2) Dynamic Loading on Bridges. Computer program DYMOL uses profilometer data which describes the bridge surface as the basis for predicting the dynamic loading caused by a vehicle crossing the bridge at a selected speed. This information has been used to suggest suitable speed limits on bridges which have experienced sagging, and to indicate the need for resurfacing bridge decks.

(3) Evaluation of Overlays on CRCP. To study the performance of asphaltic overlays on CRCP, profiles of selected test sections are being monitored on a yearly basics (Project 249, Implementation of Rigid Pavement Overlay and Design System).

(4) Updated Pavement Ride Quality Evaluation. The objective is to design and carry out an experiment to provide pavement ratings by user panels of 12 to 15 people and to obtain profile measurements on approximately 100 pavement test sections to compare with the raters ratings (Project 354, Updated Pavement Ride Quality Evaluation).

(5) Evaluation of Terminal and Initial Overlay Roughness. A series of sections will be profiled using the 690SD Profilometer. The serviceability index will be evaluated in order to have information of the level of SI (terminal SI) at which an overlay is decided.

At the same time new overlay will be profiled in order to obtain the SI after overlay (Project 400).

(6) Implementation of Rehabilitation Methods. The profile obtained with the profilometer profile can be used to estimate the quality of material needed for an efficient level-up and to overlay a section with a constant thickness. A computer program was developed, under Project 251, to calculate the material quantity (Report 251-2).

(7) Pavement Distress Mechanism. On a semi-annual basis, profilometer runs were made in connection with Project 224, "Detrimental Volume Changes of Expansive Clays in Highway Subgrades," to obtain the serviceability index changes with time.

CHAPTER 3. CORRELATION OF OLD VERSUS NEW PROFILOMETER

INTRODUCTION

This chapter describes the correlation study which was conducted between output data from the old and the new profilometers. The analysis provides the information necessary for making a smooth transition between the operational use of these two instruments.

A description of the old method for obtaining the serviceability index (SI) is also presented herein to help the reader have a better understanding of the new parameters.

The Serviceability Index (SI)

Early Method. For a number of years, the approach in Texas was to calibrate each Maysmeter independently by filtering its measurement of the test sections to the equation

$$\mathrm{Ln}\ M \cong \beta\ \mathrm{Ln}\left[\left(\frac{5}{SI}\right)\right]^{1/\alpha} \qquad (3.1)$$

where

Ln = natural logarithms

M = the Maysmeter measurement (inches per mile),

SI = the current serviceability index for the sections, and

β and α are nonlinear regression coefficients.

The value of 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 2). It contains 22 terms involving power spectral estimates computed from the digital road profile:

$$\widehat{SI2} = 5e^{-[\text{Ln } (32\ Mi)/\beta i]^{\alpha i}} \qquad (3.2)$$

The form of Eq 3.2 was obtained empirically after considerable experimentation (Ref 15) and provided each calibrated unit with an equation to convert its readings to serviceability indexes, 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 vehicle's suspension, tires, etc. due to wear or replacement of parts.

This method had some problems because several of the test sections were persistent regression outliers; that is, they deviated significantly from the calibration regression curves. A more complete explanation of the problems encountered is found in Ref 4.

The limitations of the original SI equation are not surprising because it was not developed for the Maysmeter's capabilities. Instead, power spectral and cross-spectral estimates from 64 frequency bands were considered in a later regression model, the goal being to find the 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 the Maysmeter running at 50 mph responds to a much smaller wavelength range (4 to 40 feet). Figure 3.1 shows the residual plot for the calibration session using statistic SI2. It can be observed that the residual values are very different.

Consequently, an effort was made to improve the method for predicting PSR and the Maysmeter calibration procedure. The new method is described in the first report of this project (Ref 4). It uses the root-mean-square vertical acceleration (RMSVA) for different wavelengths. In order to compute the RMSVA a computer program, VERTAC, was written. A selected sequence of base lengths ($VA_{0.5}$, VA_1, VA_2, VA_4, VA_8, VA_{16}, VA_{32}, and VA_{65}) was chosen. The subscripts represent base lengths in feet, and the units are ft/sec^2. RMSVA is described in Chapter 2 of this report.

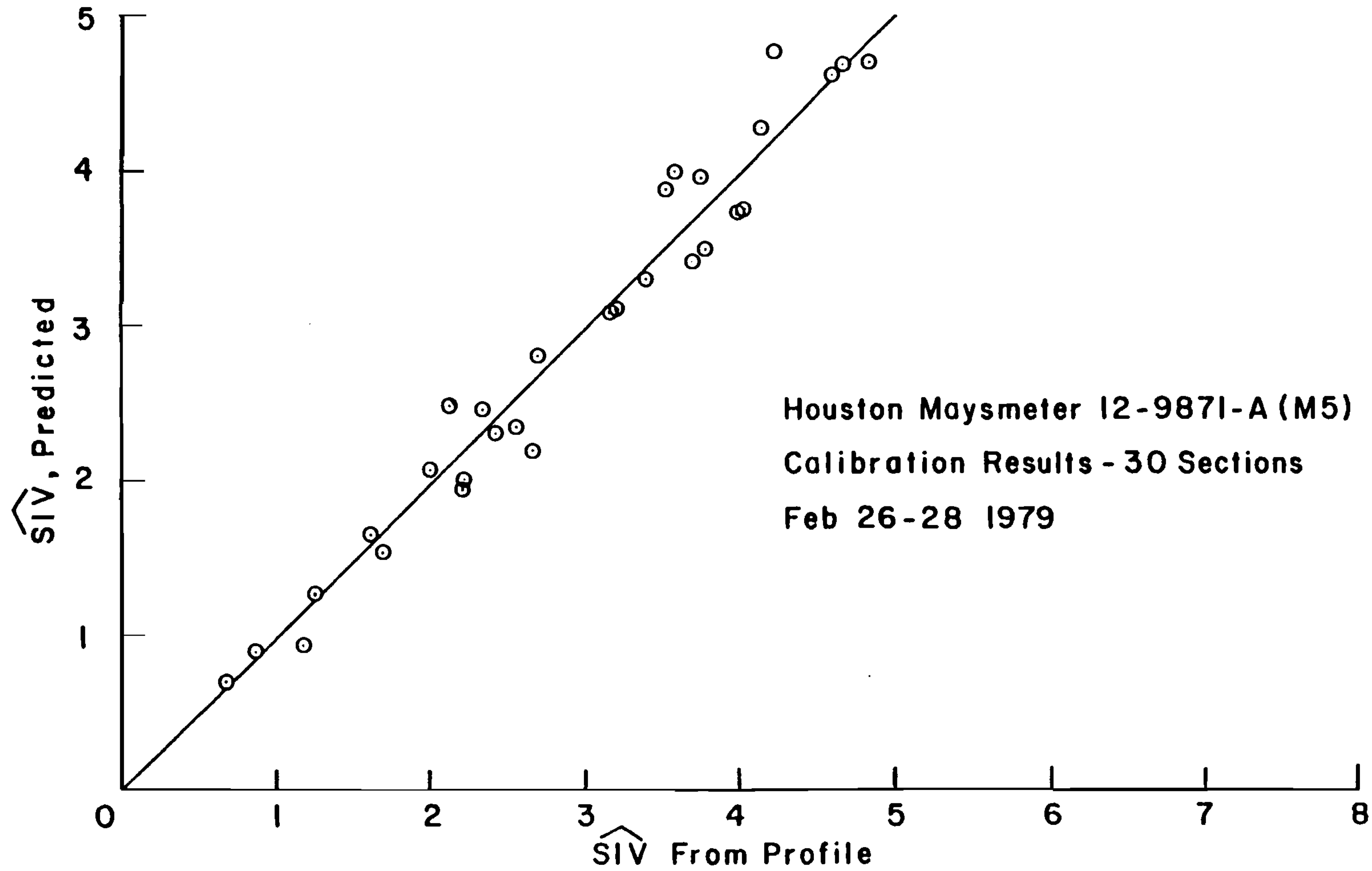

Fig 3.1. Residual plot of calibration session results for Maysmeter M5 with statistic SI2 employed as the standard (after Ref 16).

Although the RMSVA index values are well defined they are difficult to interpret by themselves. RMSVA values 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), which is a number between 0 and 5. As was described in Ref 4, a new index, SIV, was developed, based on a Maysmeter simulation value (Mo); Mo was based on two RMSVA indices:

$$Mo = -20 + 23\ VA_4 + 58\ VA_{16} \tag{3.3}$$

where VA_4 and VA_{16} are the mean wheelpath RMSVA at base lengths of 4 feet and 16 feet, respectively.

The serviceability index (SIV) was calculated as

$$SIV = 5e^{-\left[\frac{Ln(32Mo)}{8.4933}\right]^{9.3566}} \tag{3.4}$$

SIV has proved to be an effective reference for Maysmeter calibration; however, other RMSVA values calculated for different base lengths (VA_b) characterize other roughness traits which could also be used for calculating SIV.

This was accomplished by replacing the term Mo in Eq 3.4 with Mo_b, a linear function of VA_b obtained by a least-squares fitting of VA_b against Mo. The value of Mo_b in Eq 3.4 gave a SIV value in the range from 0 to 5. The equations for Mo_b are

$$Mo_1 = 16.16 + 2.94\ VA_1 \tag{3.5}$$

$$Mo_2 = -28.59 + 13.38\ VA_2 \tag{3.6}$$

$$Mo_4 = -23.51 + 34.46\ VA_4 \tag{3.7}$$

$$Mo_8 = 6.13 + 66.13\ VA_8 \tag{3.8}$$

$$Mo_{16} = 10.83 + 139.18\ VA_{16} \tag{3.9}$$

$$Mo_{32} = 10.10 + 296.66\ VA_{32} \quad (3.10)$$

$$Mo_{65} = 19.28 + 602.00\ VA_{65} \quad (3.11)$$

$$Mo_{130} = 26.30 + 1643.80\ VA_{130} \quad (3.12)$$

The predicted serviceability index ($\widehat{SIV}$) was better represented by the values of SIV from the profile, as shown in Fig 3.2, than with the $\widehat{SI2}$ values of Fig 3.1.

In this correlation study of the old and the new profilometers another set of equations has been developed following the approach described above.

Factorial Experiment

In order to compare the profile data from the old and the new profilometers and develop a reliable regression equation, a factorial experiment was used. Factorial experimentation is a systematic method of investigating the relationships among the effects of different influencing factors or variables. In the present study a series of variables was selected for evaluation; they are described herein.

DESCRIPTION OF THE FACTORIAL EXPERIMENT

At the outset of the analysis, the main variables considered in the factorial experiment were

(1) pavement type: flexible and rigid;
(2) surface type (texture): coarse and fine;
(3) roughness level: smooth and rough;
(4) profilometer speed: 20 and 34 mph;
(5) temperature level; high and low;
(6) surface condition: cracked and uncracked;
(7) lane: inside and outside;
(8) sampling frequency: 2, 2.02, and 6-inch sections;

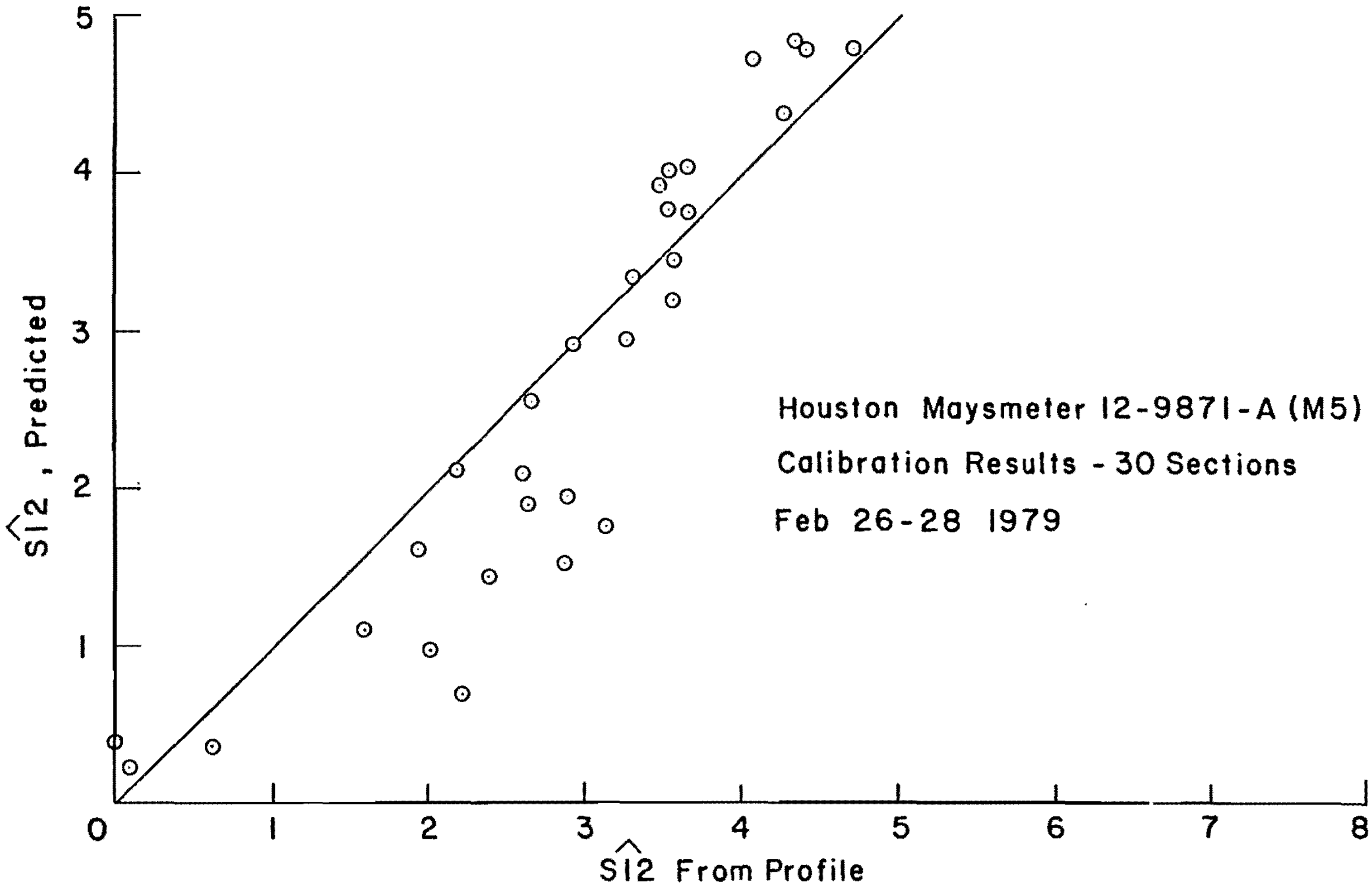

Fig 3.2. Residual plot of calibration session results for Maysmeter M5 with RMSVA SIV employed as the standard (after Ref 16).

(9) accelerometer filter wavelength: 200 and 300 feet; and

(10) calibration distance: 0.2 and 0.4 mile.

Upon more detailed study of these ten parameters, it became apparent that inclusion of the factors (1) temperature level, (2) surface condition (texture), and (3) lane was unnecessary, given the nature of the experiment. For example, since the two profilometers would be run successively over the same surface, with one profilometer immediately following the other, the pavement texture and temperature at a given time would be approximately the same. Therefore, it was reasonable to assume that surface condition and temperature would not be significant factors in the correlation analysis. Similarly, the two profilometers travelled along the same lane; hence two levels for this parameter were not needed.

It was subsequently decided to set the level values of various factors as follows:

(1) Sampling frequency: old profilometer = 6.00-inch
new profilometer = 6.00-inch

(2) Accelerometer filter wavelength: new profilometer = 200 ft
old profilometer = fixed at 200 ft

(3) Calibration distance: 0.2-mile sections

(4) Profilometer speed: 20 mph for both profilometers.

It was not deemed feasible to consider a profilometer speed of 34 mph in the experiment, because at that speed the probability of damage to the potentiometers on very rough sections was high, and erroneous measurement of the profile because of bouncing of the tracking wheel was likely to occur.

Because of limitations in the number of pavement sections available for the experiment, the final factorial layout is the one given in Table 3.1. When high discrepancies were found in the two profilometer runs for any pavement section, an additional run had to be conducted with both

TABLE 3.1. ROAD SECTIONS USED IN THE FACTORIAL EXPERIMENT FOR THE CORRELATION OF OLD VS. NEW PROFILOMETER.

	Type of Pavement		
		Flexible	
SIV Range	Rigid	Surface Texture Coarse	Surface Texture Fine
4.01 - 5.00		ATS 23, ATS 36	ATS 7, ATS 32
3.01 - 4.00	M2, M4, M5, M6, M7	ATS 3, ATS 8, ATS 19, ATS 41	ATS 5, ATS 10, ATS 28 ATS 40, ATS 34
2.01 - 3.00	M3, M8, M9, M10, M11, M12, M14, M 15	ATS 2, ATS 6, ATS 14	ATS 35
1.01 - 2.00		ATS 15, ATS 38	ATS 44
0.00 - 1.00		ATS 39, ATS 45	

profilometers in order to have a basis for discarding profiles with unusual discrepancies.

According to Table 3.1, the inference space for the rigid-pavement sections has an SI range from 2 to 4. In the case of the flexible-pavement sections, very few sections could be found for an SI range from 0 to 1. Tables 3.2 to 3.5 present the observed RMSVA values for the new and old profilometers, which were used in the regression analysis.

General Regression Equations

Originally, it was hoped that one regression equation would be adequate for the whole factorial experiment. However, very low values for the coefficient of correlation were obtained in numerous attempts to find a single regression equation. Therefore, the data were divided into two groups, flexible and rigid pavements, and a regression equation for each group was obtained after extensive statistical analysis using a step-wise regression technique. The general form of these regression equations is

$$\widehat{SIV} = C_0 + C_1 VA_1 + C_2 VA_2 + \ldots + C_n VA_n + \epsilon \qquad (3.13)$$

where

$C_1, C_2 \ldots C_n$ are regression constants,

VA_i = RMSVA for a base $length_i$ from the new profilometer,

C_o = the intercept of the estimated regression line at the origin, and

ϵ = the residual estimating SIV.

The equations for each pavement type are given below. Equation 3.14 can be used to predict the $\widehat{SIV}$ for flexible pavement, whereas Eq 3.15 is applicable for rigid-pavement sections:

TABLE 3.2 OLD PROFILOMETER SIV AND RMSVA FOR FLEXIBLE PAVEMENT

Section Number	SIV Values	Base Length, Feet								
		0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
23	4.11	57.70	18.55	5.390	1.748	.6911	.3309	.1659	.0832	.0232
23	4.13	50.02	16.71	5.199	1.719	.6735	.3292	.1672	.0863	.0256
36	4.41	72.58	20.09	4.901	1.431	.4906	.2612	.1748	.0890	.0254
36	4.44	72.28	20.32	4.916	1.393	.4837	.2593	.1748	.0890	.0254
37	4.48	37.01	11.02	3.514	1.193	.5345	.3142	.1791	.0900	.0295
37	4.47	35.82	10.87	3.527	1.188	.5429	.3221	.1834	.0905	.0292
3	3.17	131.89	36.18	10.337	2.950	1.0602	.5032	.2513	.1224	.0518
3	3.33	95.23	28.70	9.203	2.708	.9881	.4793	.2412	.1154	.0486
8	3.64	55.55	17.62	5.501	2.195	1.0568	.4616	.2032	.0857	.0256
8	3.66	55.91	17.97	5.514	2.185	1.0460	.4545	.2045	.0912	.0312
9	3.12	63.85	21.57	7.372	3.021	1.1290	.5153	.2220	.1132	.0308
9	3.19	63.40	21.20	7.358	2.912	1.1077	.5009	.2170	.1108	.0311
19	3.58	78.07	23.57	7.050	2.313	.8713	.4592	.2456	.1011	.0370
19	3.56	77.90	24.03	7.165	2.338	.8774	.4611	.2486	.0983	.0344
41	3.50	90.14	28.96	8.222	2.498	.8894	.4415	.2575	.1383	.0554
41	3.46	97.24	30.50	8.692	2.569	.8985	.4416	.2596	.1371	.0504
2	2.36	126.86	38.48	11.445	4.200	1.6703	.7148	.3176	.1654	.0822
2	2.39	124.19	38.07	11.268	4.153	1.6329	.7036	.3116	.1621	.0835
6	2.56	63.42	23.44	8.892	3.592	1.4896	.7599	.3884	.1460	.0482
6	2.45	66.99	24.93	9.230	3.737	1.5969	.8119	.4150	.1578	.0488
14	2.93	96.05	28.06	8.174	2.974	1.3354	.6850	.3068	.1490	.0338
14	2.94	87.83	26.10	7.769	2.977	1.3468	.6754	.2977	.1400	.0314
15	1.67	150.76	55.03	19.989	6.530	2.0151	.6222	.2290	.1073	.0300
15	1.19	171.32	65.20	23.721	7.992	2.4634	.8480	.2675	.1218	.0395
38	1.78	112.26	40.80	13.985	5.502	1.8655	.8677	.3442	.1388	.0391
38	1.82	109.65	39.47	13.498	5.379	1.8347	.8643	.3613	.1486	.0437

(continued)

TABLE 3.2 (CONT.)

Section Number	SIV Values	Base Length, Feet 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
39	.77	163.85	56.20	21.302	9.058	4.3311	1.4762	.5438	.1741	.0656
39	.79	161.02	55.00	20.876	8.952	4.2800	1.4659	.5300	.1614	.0598
45	.46	112.61	40.61	18.052	9.318	5.1491	2.6481	1.0665	.3364	.0966
45	.46	105.87	38.87	17.615	9.347	5.1942	2.6685	1.0661	.3408	.0995
7	4.79	29.86	9.61	2.738	.870	.3859	.2342	.1475	.0838	.0211
7	4.76	31.55	10.55	2.971	.913	.3949	.2333	.1475	.0834	.0196
32	4.37	43.72	12.95	3.714	1.290	.5418	.3468	.2632	.1696	.0690
32	4.41	41.94	12.42	3.434	1.221	.5251	.3485	.2677	.1731	.0724
33	4.37	38.62	11.84	3.486	1.340	.6329	.3226	.1624	.0808	.0193
33	4.36	39.61	12.44	3.560	1.358	.6297	.3246	.1651	.0823	.0200
5	3.39	126.87	36.50	9.680	2.993	.8938	.3237	.1533	.0750	.0208
5	3.41	124.46	36.50	9.442	2.943	.8771	.3237	.1538	.0756	.0204
10	3.68	52.16	17.28	6.026	2.257	.8267	.4117	.2070	.0928	.0321
10	3.69	51.74	17.43	6.140	2.267	.8152	.3980	.2025	.0924	.0318
28	3.10	129.39	37.89	9.872	2.949	1.1187	.5555	.2497	.0805	.0184
28	3.06	128.41	38.37	9.969	3.026	1.1290	.5592	.2508	.0807	.0181
40	3.63	92.45	25.86	7.217	2.268	.8141	.4395	.3256	.2169	.0964
40	3.61	94.47	26.98	7.426	2.311	.8277	.4355	.3167	.2117	.0947
34	3.85	45.91	15.50	5.448	2.030	.7604	.3876	.2126	.0909	.0320
34	3.90	46.35	15.49	5.269	1.932	.7536	.3907	.2201	.0932	.0311
35	2.67	117.32	39.34	11.120	3.706	1.3736	.6130	.3061	.1381	.0523
35	2.68	121.54	39.75	10.748	3.689	1.3677	.6163	.2978	.1397	.0522
44	1.24	93.23	31.10	11.019	5.200	3.0235	1.8639	1.0066	.5273	.1341
44	1.24	91.06	30.44	11.002	5.203	3.0175	1.8626	1.0080	.5271	.1437

TABLE 3.3. OLD PROFILOMETER SIV AND RMSVA FOR RIGID PAVEMENT

Section Number	SIV	Base Length, Feet 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
2	3.97	49.93	15.26	5.295	2.068	.8302	.2894	.1250	.0498	.0179
2	3.97	50.40	15.42	5.397	2.084	.8222	.2861	.1184	.0457	.0123
4	3.03	98.12	25.39	8.125	3.136	1.3264	.5339	.1944	.0929	.0395
4	3.08	86.49	23.26	7.756	3.039	1.3097	.5339	.1914	.0815	.0346
5	3.03	98.79	29.31	9.631	3.465	1.2710	.4072	.1669	.0656	.0309
5	3.04	91.75	28.19	9.395	3.428	1.2698	.4100	.1704	.0710	.0342
6	3.65	46.10	15.97	5.530	2.201	.9506	.4543	.1752	.0852	.0380
6	3.62	47.01	16.13	5.696	2.253	.9644	.4550	.1749	.0867	.0389
7	3.48	69.82	26.91	6.670	2.402	.9954	.4927	.2101	.0835	.0346
7	3.46	73.85	28.40	6.844	2.435	1.0108	.4954	.2102	.0831	.0333
3	2.85	86.40	26.10	8.486	3.229	1.3747	.6445	.3200	.1590	.0895
3	2.92	87.63	25.77	8.379	3.157	1.3197	.6197	.3105	.1454	.0811
8	2.86	98.20	32.53	10.291	3.820	1.3303	.4047	.1374	.0553	.0268
8	2.80	107.86	34.13	10.705	3.926	1.3511	.4168	.1415	.0587	.0284
9	2.87	86.46	23.84	8.315	3.235	1.3735	.6329	.2374	.1037	.0420
9	2.83	93.15	25.16	8.582	3.292	1.3866	.6425	.2437	.1069	.0438
10	2.56	73.28	20.15	7.295	3.315	1.6206	.8738	.3844	.1044	.0272
10	2.55	68.90	19.65	7.204	3.330	1.6193	.8761	.3893	.1107	.0325
11	2.48	104.32	33.80	11.500	4.281	1.5060	.5684	.2924	.1234	.0587
11	2.57	89.99	30.12	10.676	4.076	1.4762	.5646	.3091	.1393	.0683
12	2.37	122.34	37.12	12.389	4.067	1.6449	.7579	.2738	.0909	.0284
12	2.44	113.82	33.20	11.371	3.902	1.6302	.7527	.2788	.0995	.0339
14	2.24	109.17	33.70	11.877	4.831	1.9235	.5844	.2569	.1177	.0383
14	2.22	97.80	32.07	11.538	4.880	1.9814	.5911	.2577	.1165	.0399
15	2.34	109.66	34.32	11.429	4.664	1.8701	.5526	.2147	.1092	.0506
15	2.40	86.51	29.27	10.511	4.512	1.8384	.5499	.2095	.1051	.0516

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TABLE 3.4. NEW PROFILOMETER RMSVA VALUES FOR FLEXIBLE PAVEMENT

Section Number	Base Length, Feet								
	0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
23	84.13	26.20	7.550	2.332	.7705	.3513	.1639	.0687	.0130
23	86.24	26.23	7.876	2.360	.7868	.3506	.1675	.0726	.0137
36	93.49	26.63	6.684	1.713	.5347	.2579	.1641	.0717	.0149
36	94.09	26.85	6.646	1.774	.5425	.2625	.1642	.0708	.0152
37	52.30	14.02	4.228	1.372	.5499	.3162	.1714	.0754	.0157
37	51.87	13.97	4.202	1.357	.5485	.3164	.1721	.0755	.0158
03	112.15	35.41	10.182	3.030	1.0274	.4729	.2247	.0814	.0271
03	110.72	32.16	9.425	2.929	1.0115	.4799	.2302	.0796	.0264
08	76.69	22.47	6.691	2.540	1.1248	.4773	.1988	.0768	.0183
08	74.87	22.13	6.559	2.482	1.1243	.4762	.2010	.0779	.0178
09	80.19	25.19	8.227	3.167	1.1591	.5201	.2123	.1002	.0192
09	78.75	25.69	8.435	3.180	1.1093	.5003	.2086	.1009	.0191
19	98.61	29.70	8.578	2.646	.9318	.4707	.2376	.0793	.0199
19	98.03	29.93	8.404	2.577	.9344	.4705	.2480	.0823	.0205
41	118.48	35.36	10.322	2.859	.9329	.4353	.2460	.1066	.0259
41	115.25	35.42	10.323	2.878	.9303	.4409	.2487	.1092	.0259
02	147.29	45.55	13.511	4.747	1.7524	.7076	.2881	.1122	.0385
02	147.74	46.10	13.461	4.732	1.7549	.7214	.2890	.1115	.0374
06	89.06	29.96	10.762	4.065	1.5779	.8102	.3945	.1282	.0267
06	85.27	29.16	10.510	3.935	1.6410	.8355	.4045	.1303	.0268
14	114.24	37.73	10.798	3.534	1.4268	.7079	.3061	.1354	.0204
14	110.26	35.58	10.214	3.450	1.4043	.7034	.3024	.1324	.0201
15	191.99	67.36	23.753	7.952	2.4652	.7890	.2445	.1034	.0265
15	204.91	69.29	24.163	8.125	2.5004	.8050	.2638	.1064	.0247
38	126.74	44.86	14.905	5.543	1.8683	.8407	.3137	.1112	.0211
38	126.20	43.99	14.586	5.493	1.8215	.8310	.3202	.1170	.0214

(continued)

TABLE 3.4. (CONT.)

Section Number	Base Length, Feet								
	0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
39	235.12	69.64	23.765	9.363	4.3316	1.4792	.5409	.1276	.0310
39	199.35	63.76	22.823	9.356	4.3613	1.4901	.5481	.1312	.0311
45	137.53	45.25	20.888	10.435	5.3935	2.6786	1.0508	.2838	.0652
45	158.73	49.99	21.147	10.475	5.4586	2.7318	1.0619	.2857	.0652
7	44.56	13.67	3.648	1.106	.4158	.2395	.1453	.0743	.0116
7	47.13	14.05	3.730	1.100	.4156	.2409	.1429	.0724	.0115
32	56.15	14.32	4.116	1.360	.5007	.3041	.2162	.1288	.0342
32	56.51	14.84	4.186	1.352	.4994	.3038	.2148	.1275	.0339
33	69.08	20.24	5.451	1.734	.6755	.3275	.1552	.0655	.0121
33	65.29	19.27	5.372	1.711	.6780	.3281	.1533	.0648	.0119
5	157.41	45.12	12.852	3.735	1.0615	.3581	.1581	.0738	.0142
5	165.46	47.43	13.135	3.896	1.0811	.3696	.1551	.0732	.0150
10	66.24	20.71	7.056	2.699	.9169	.4368	.2106	.0811	.0184
10	64.40	19.82	6.841	2.583	.8782	.4238	.1974	.0788	.0183
28	157.99	46.95	13.221	3.793	1.2543	.5736	.2574	.0801	.0132
28	159.56	46.52	13.307	3.838	1.2873	.5885	.2625	.0800	.0133
40	112.02	32.99	9.794	2.815	.9186	.4127	.2638	.1487	.0485
40	112.36	33.71	9.863	2.861	.9124	.4127	.2635	.1493	.0487
34	60.27	18.08	5.691	2.038	.7672	.3934	.2189	.0827	.0185
34	60.44	18.63	5.891	2.154	.7864	.3852	.2124	.0812	.0187
35	140.72	43.18	13.567	4.376	1.5218	.6692	.3097	.1221	.0262
35	142.00	44.38	13.702	4.468	1.5406	.6698	.3053	.1172	.0150
44	99.20	32.59	12.453	5.620	3.1605	1.8945	.9588	.4497	.0808
44	102.34	32.17	12.251	5.643	3.1729	1.9067	.9506	.4422	.0786

TABLE 3.5. NEW PROFILOMETER RMSVA VALUES FOR RIGID PAVEMENTS

Section Number	Base Length, Feet								
	0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
2	81.77	20.25	6.607	2.404	.8799	.3036	.1241	.0424	.0081
2	97.69	24.89	7.564	2.591	.9112	.3091	.1247	.0422	.0078
4	128.91	31.59	9.750	3.477	1.4116	.5563	.1892	.0634	.0194
4	122.05	33.08	9.875	3.579	1.4358	.5611	.1913	.0645	.0190
5	228.68	75.43	20.479	5.871	1.7734	.5271	.1774	.0555	.0164
5	218.51	67.29	18.677	5.577	1.6910	.5069	.1793	.0551	.0152
6	75.01	20.25	6.791	2.565	1.0193	.4706	.1667	.0613	.0199
6	77.23	21.15	6.961	2.556	1.0268	.4766	.1687	.0617	.0201
7	102.50	33.03	8.154	2.750	1.0683	.5146	.2123	.0672	.0148
7	90.44	29.21	7.843	2.674	1.0437	.5101	.2093	.0642	.0139
3	112.18	30.87	9.520	3.347	1.3802	.6458	.2781	.0925	.0318
3	108.66	31.77	9.748	3.424	1.3745	.6331	.2737	.0892	.0313
8	204.39	81.08	22.911	6.502	1.8308	.5237	.1529	.0459	.0140
8	190.81	77.14	21.178	6.205	1.7720	.5205	.1581	.0469	.0150
9	130.30	37.20	11.447	3.941	1.4992	.6679	.2309	.0855	.0186
9	143.90	35.40	11.321	3.942	1.4901	.6692	.2319	.0859	.0198
10	104.86	28.09	8.779	3.734	1.7157	.9482	.4156	.1021	.0203
10	109.79	28.56	8.991	3.767	1.7192	.9197	.3977	.1006	.0207
11	121.61	35.50	11.846	4.336	1.5063	.5719	.2815	.0954	.0261
11	132.76	38.25	12.506	4.481	1.5277	.5778	.2840	.0967	.0262
12	168.64	48.60	12.761	4.410	1.7100	.7684	.2704	.0812	.0181
12	171.64	47.71	13.792	4.424	1.7163	.7703	.2721	.0774	.0174
14	153.03	48.51	15.443	5.742	2.1791	.6223	.2697	.1002	.0195
14	149.91	42.04	13.892	5.356	2.0613	.6138	.2638	.0964	.0194
15	151.00	52.84	15.901	5.704	2.0588	.5889	.2003	.0712	.0235
15	130.11	42.91	13.757	5.375	2.0142	.5906	.2029	.0723	.0232

$$\widehat{SIV}_F = 5.029 - 0.424\ VAN_4 - 2.702\ VAN_{64} \quad (3.14)$$

$$R^2 = 0.938 \qquad SE = 0.299\ ft^2/sec^2$$

where

$\widehat{SIV}_F$ = predicted serviceability index for flexible pavements,

VAN_4 = RMSVA for a 4-foot base length from the new profilometer, ft^2/sec^2, and

VAN_{64} = RMSVA for a 64-foot base length from the new profilometer, ft^2/sec^2.

and

$$\widehat{SIV}_R = 5.244 - 1.027\ VAN_8 - 10.332\ VAN_{64} \quad (3.15)$$

$$R^2 = 0.936 \qquad SE = 0.135\ ft^2/sec^2$$

where

$\widehat{SIV}_R$ = predicted serviceability index for rigid pavements,

VAN_8 = RMSVA for an 8-foot base length from the new profilometer, ft^2/sec^2, and

VAN_{64} = RMSVA for a 64-foot base length from the new profilometer, ft^2/sec^2.

It can be observed that excellent R-square values have been obtained for both equations with reasonable values of standard error.

Figures 3.3 and 3.4 show the predicted versus the actual SI values for flexible and rigid pavements, respectively. Most of the data points lie on the line of equality. Plots of residual versus predicted values of SIV were also prepared for both pavement types and they are shown in Figs 3.5 and 3.6.

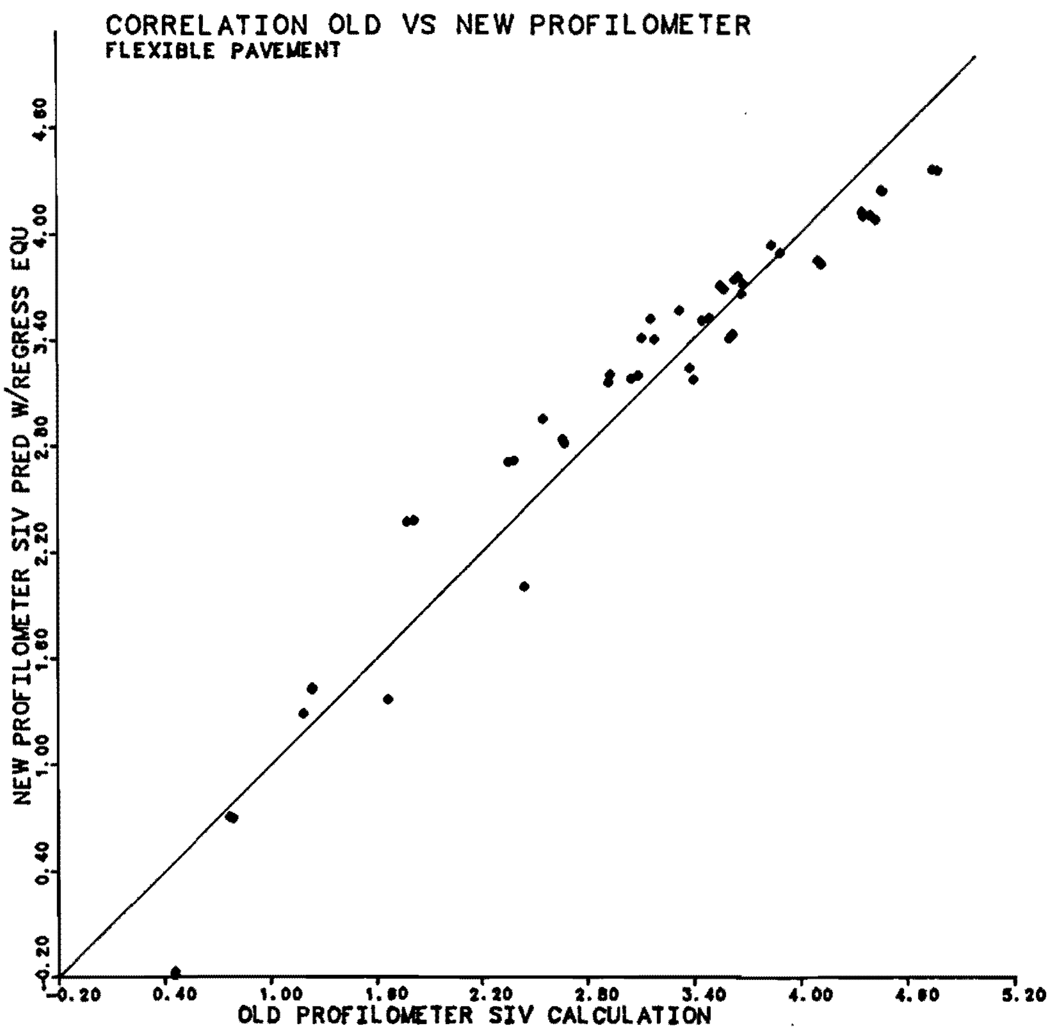

Fig 3.3. New and old profilometer correlation for flexible pavements.

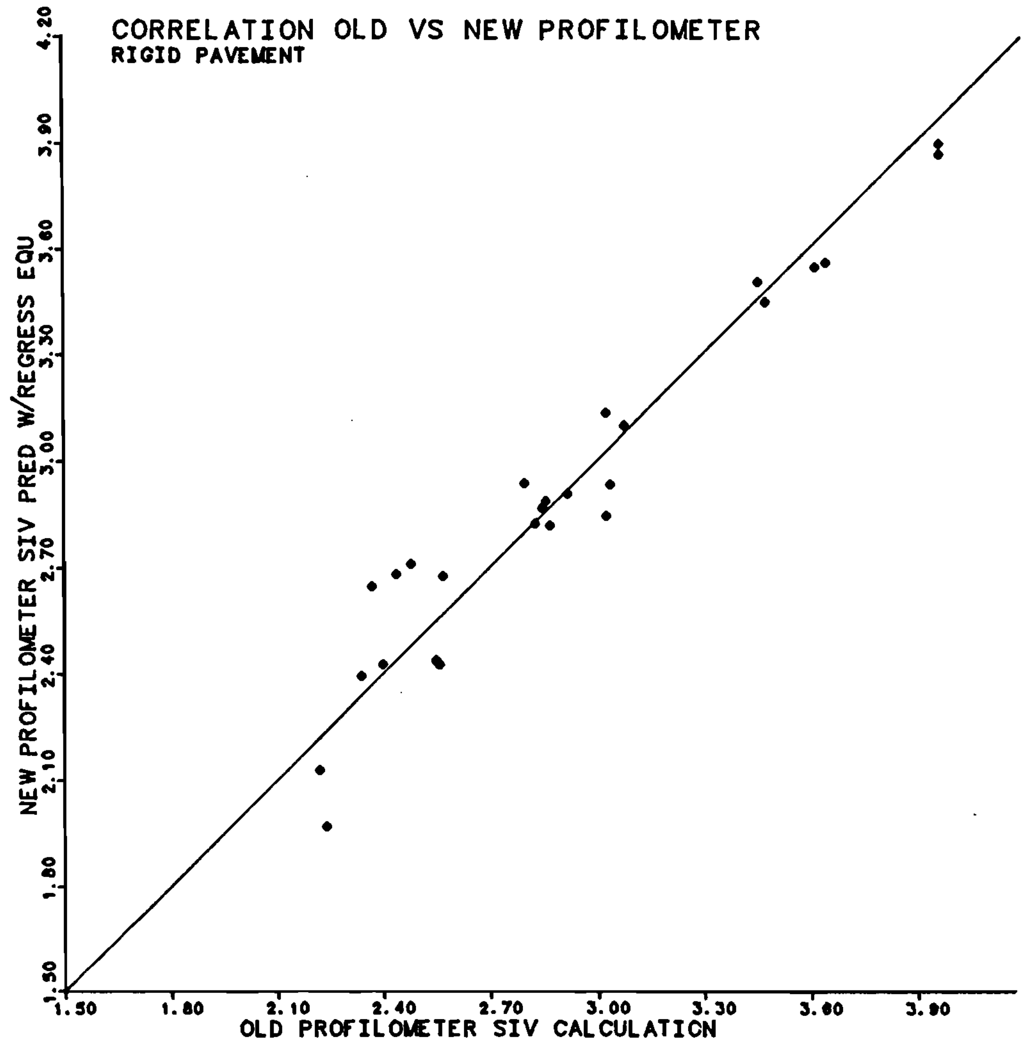

Fig 3.4. New and old profilometer correlation for rigid pavement.

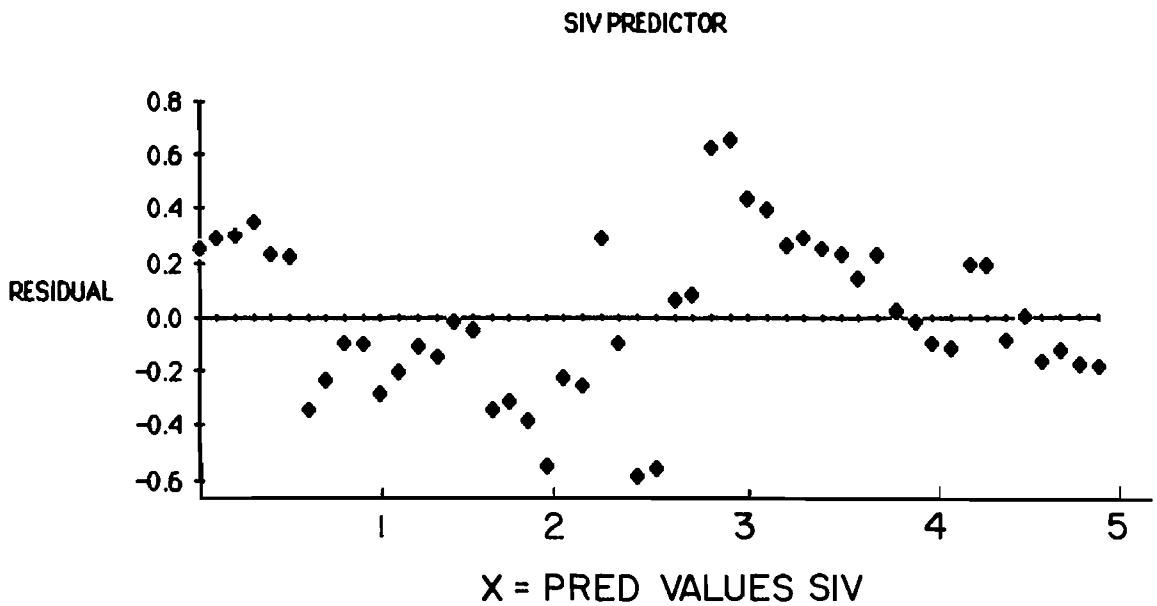

Fig 3.5. Residuals versus Serviceability Index (SIV) for flexible pavements measured with the new profilometer at 20 mph with 200 feet W.L.F.

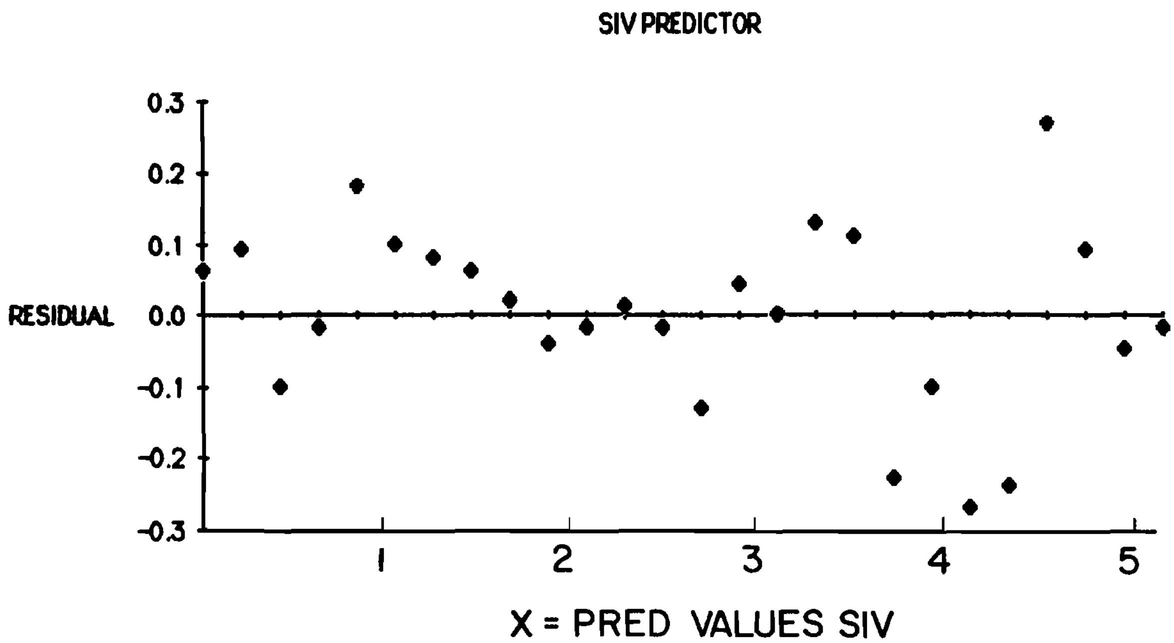

Fig 3.6. Residual versus Serviceability Index (SIV) for rigid pavement measured with the new profilometer at 20 mph with 200 feet W.L.F.

It can be concluded, from both plots, that the residuals vary randomly with the predicted values of SIV.

<u>Correlation of RMSVA Values from the New and the Old Profilometers</u>

The purpose of this analysis is to provide a basis for relating the RMSVA values from two different profilometers. This will make it possible to continue to utilize the extensive data sets that have been gathered by the old profilometer during the past several years.

A regression equation which uses new profilometer RMSVA values to predict te RMSVA values that would result from old profilometer measurements for different base lengths has been developed. The form of the general equation is

$$\hat{VA}_b = C_0 + C_1 \; VAN_b + \qquad (3.16)$$

where

$\hat{VA}_b$ = predicted value of RMSVA from the old profilometer measurements for base length b, ft^2/sec^2,

VAN_b = RMSVA value measured by the new profilometer for base length b, ft^2/sec^2,

C_o = the intersept of estimated regression line at the origin,

C_1 and C_2 = regression coefficients, ft^2/sec^2, and

ϵ = the residual estimating VA_b.

Table 3.6 presents the values of the various parameters which were used in developing Eq 3.16 for flexible pavements. Values for the standard error and the coefficients of determination are also shown. Table 3.7 includes similar information for rigid pavements. Figure 3.7 is a plot of the coefficient of determination (R^2) versus the base length for both pavement types. It can be observed that, in general, significantly higher

TABLE 3.6. FLEXIBLE PAVEMENT REGRESSION COEFFICIENTS

VA_b	C_o	C_1	Standard Error	Determination Coefficient R^2
0.5	-2.66	0.820	10.09	93.0
1.0	-1.77	0.882	2.54	96.3
2.0	-0.747	0.910	0.87	97.0
4.0	-1.97	0.939	0.26	98.6
8.0	-0.296	0.966	0.07	99.6
16.0	0.0004	0.981	0.03	99.7
32.0	0.005	1.02	0.018	99.3
64.0	0.0025	1.19	0.013	98.0
128.0	0.0008	1.76	0.007	94.0

TABLE 3.7. RIGID PAVEMENT REGRESSION COEFFICIENTS

VA_b	C_o	C_1	Standard Error	Determination Coefficient R^2
0.5	36.6	0.369	14.70	52.0
1.0	16.3	0.256	4.84	44.6
2.0	4.76	0.339	1.613	47.3
4.0	1.12	0.552	0.492	66.3
8.0	0.144	0.810	0.132	83.5
16.0	-0.352	0.996	0.035	94.6
32.0	0.0018	1.00	0.016	95.2
64.0	0.0011	1.28	0.014	74.5
128.0	-0.0142	2.85	0.006	85.1

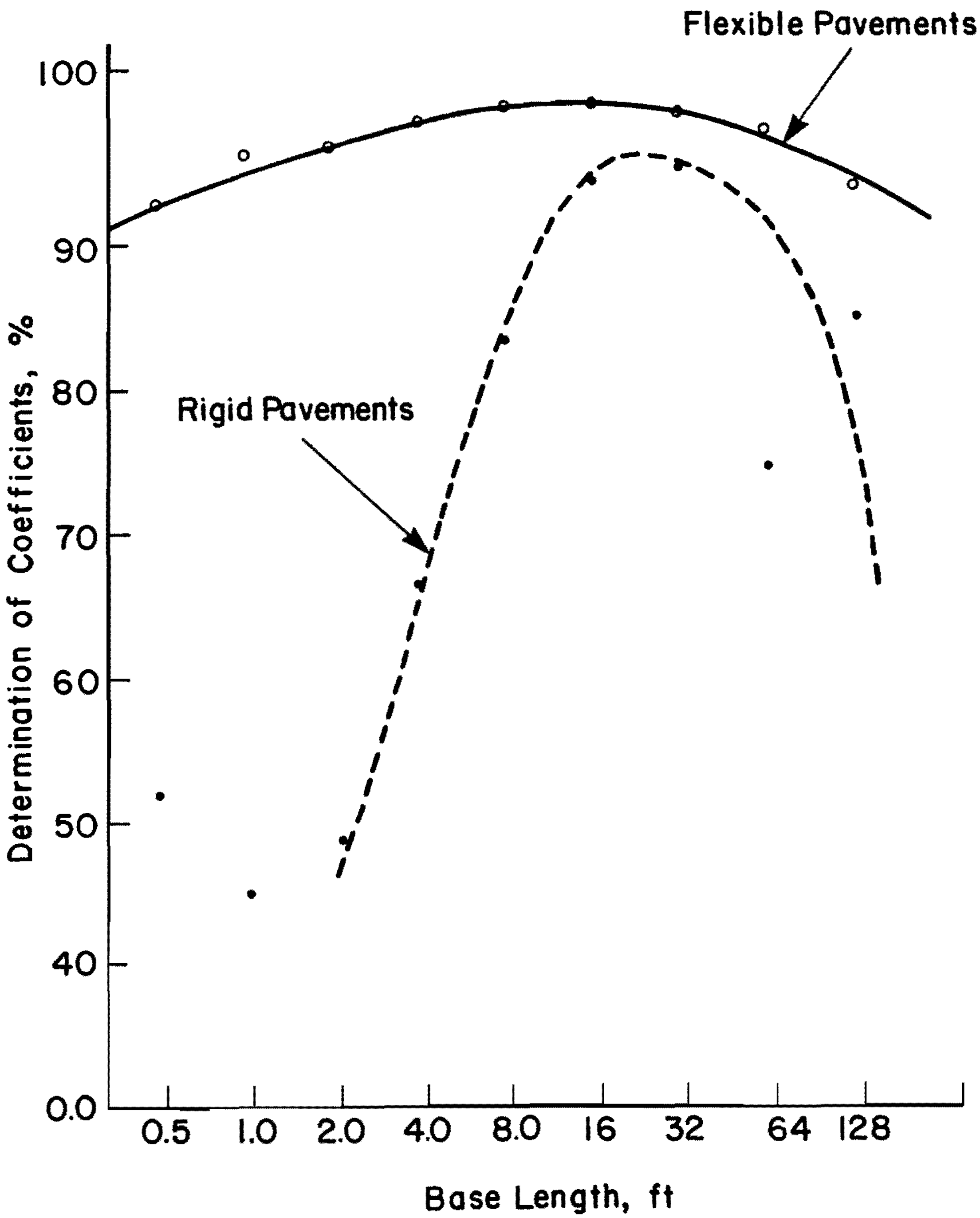

Fig 3.7. Determination coefficients (R^2) versus base length for rigid and flexible pavements.

coefficients of determination were obtained for flexible pavements. Appendix G contains a series of plots of old versus new RMSVA's for the different base lengths and type of pavement (flexible and rigid).

Maysmeter Simulation by Means of the RMSVA from the New Profilometer

As explained above in the section on the serviceability index, a Maysmeter prediction was developed using RMSVA values from the old profilometer (Eq 3.3). This equation needed to be modified to perform properly when using values for the RMSVA from the new profilometer. The modified equations for flexible and rigid pavements are given below:

$$CMo_F = -24.5078 + 21.597\ VAN_4 + 56.899\ VAN_{16} \quad (3.17)$$

where

CMo_F = corrected Maysmeter predicted value for flexible pavements, in./mile,

VAN_4 = RMSVA from the new profilometer for a 4-foot base length, ft^2/sec^2, and

VAN_{16} = RMSVA from the new profilometer for a 16-foot base length, ft^2/sec^2.

and

$$CMo_R = 3.7184 + 12.696\ VAN_4 + 57.768\ VAN_{16} \quad (3.18)$$

where

CMo_R = corrected Maysmeter predicted value for rigid pavements, in/mile.

TABLE 3.8. CORRECTED MAYSMETER SIMULATION VALUES FOR DIFFERENT VALUES OF BASE LENGTH

Base Length, (Feet)	Type of Pavement: Flexible	Type of Pavement: Rigid
1.0	$CMO_1 = 10.96 + 2.593\ VAN_1$	$CMO_1 = 64.08 + 0.752\ VAN_1$
2.0	$CMO_2 = 38.58 + 12.17\ VAN_2$	$CMO_2 = 35.09 + 4.535\ VAN_2$
4.0	$CMO_4 = 30.29 + 32.35\ VAN_4$	$CMO_4 = 37.48 + 30.06\ VAN_4$
8.0	$CMO_8 = 4.173 + 63.88\ VAN_8$	$CMO_8 = 15.65 + 53.56\ VAN_8$
16.0	$CMO_{16} = 10.885 - 136.53\ VAN_{16}$	$CMO_{16} = 5.931 + 138.6\ VAN_{16}$
32.0	$CMO_{32} = 11.583 + 302.59\ VAN_{32}$	$CMO_{32} = 10.633 + 296.66\ VAN_{32}$
64.0	$CMO_{64} = 20.78 + 716.73\ VAN_{64}$	$CMO_{64} = 25.902 + 770.56\ VAN_{64}$
128.0	$CMO_{128} = 27.61 + 2877.24\ VAN_{128}$	$CMO_{128} = 2.96 + 4684.8\ VAN_{128}$

Table 3.8 gives the values of the corrected Mo for different base lengths, which correspond to Eqs 3.5 to 3.12 for the new profilometer RMSVA. These values were calculated for flexible and rigid pavements.

Correlation of the Maysmeter Index (MMI) and the Maysmeter Simulation (Mo)

The Maysmeter index (MMI) is calculated by the profilometer's on-board computer, using Maysmeter simulation software developed by K. J. Law Engineers, Inc. Although the MMI values measured on the Austin test sections are considerably higher than those used for Maysmeter calibration (Mo), the analysis shows that the relationship between values obtained from the two systems on a given section is linear.

Using the data obtained during the profilometer correlation, a regression analysis was performed for flexible pavements.

The regression equation is

$$CMo_F = -9.33 + 0.810\ (MMI) \tag{3.19}$$

$$R^2 = 0.99$$

where

CMo_F = corrected Maysmeter simulated value for flexible pavements, in inch/mile, and

MMI = Maysmeter index in inch/mile.

The results of the linear regression analysis gave a very high correlation of determination ($R^2 = 0.99$). Figure 3.8 shows the plot of the data points and the regression equation.

Since we have already described an expression for serviceability index (SIV) in terms of Mo (Eq 3.4), an algebraic substitution yields an equation defining the serviceability estimate as a function of MMI, which is called SID_F:

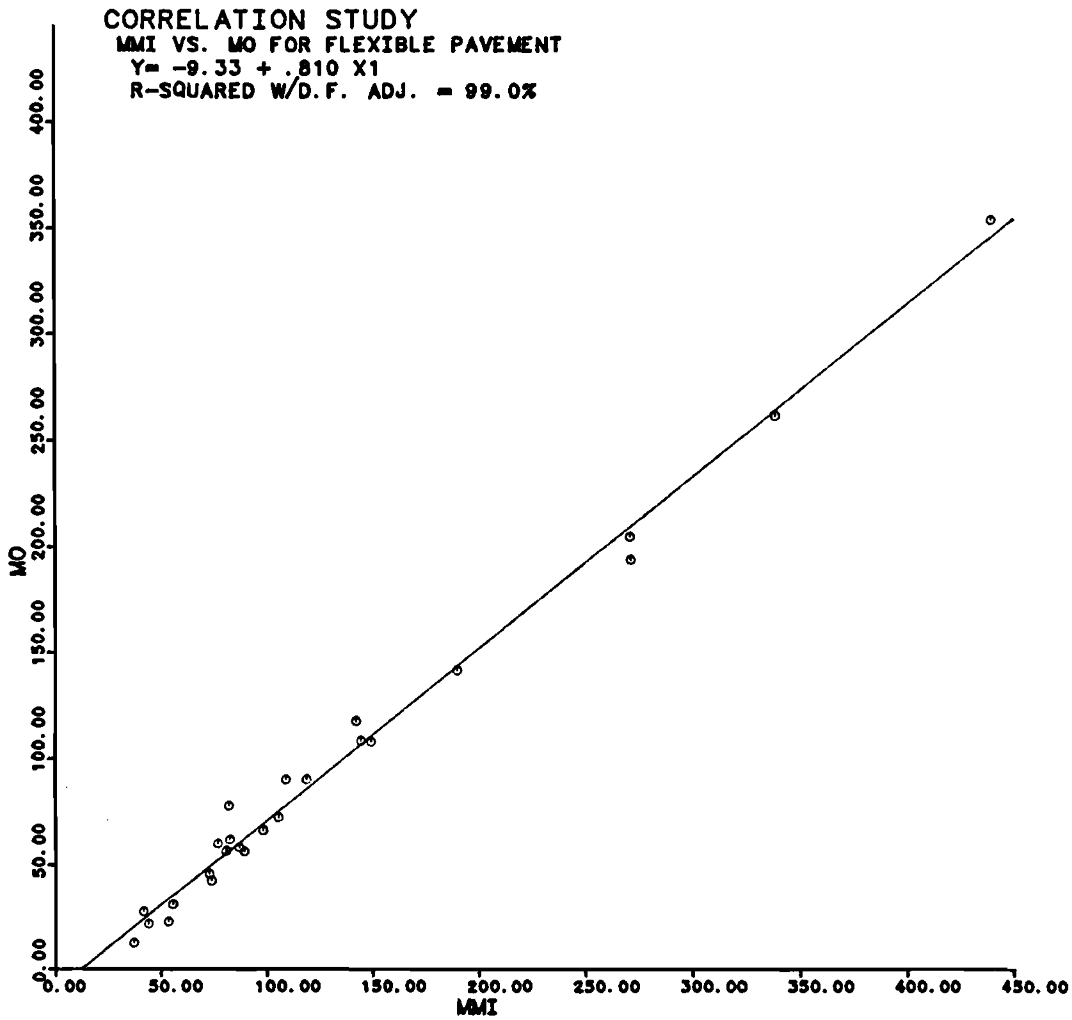

Fig 3.8. Maysmeter Index (MMI) versus Maysmeter Simulation (Mo) Relationship.

$$SID_F = 5e^{-\left[\frac{Ln\ (25.92\ MMI\ -\ 298.56)}{8.4933}\right]^{9.3566}} \qquad (3.20)$$

where

SID_F = serviceability index predicted with MMI,

MMI = Maysmeter index from the new 690D profilometer,

e = the base of natural logarithm, and

Ln = natural logarithm.

It should emphasize that this method of approximating SI should be used only when a quick result is needed and the normal procedure using RMSVA should be used in any other case.

CHAPTER 4. NON-CONTACT TRANSDUCERS IN ROAD PROFILING

INTRODUCTION

The purpose of this chapter is to present the results of an investigation of the feasibility of using non-contact transducers to replace the tracking wheels on the Surface Dynamic profilometer. A laser, an infrared and a high intensity light device were each evaluated in this study. Information is given about the use of non-contact transducer devices connected to the high-speed profilometer for the purpose of measuring the road profile. The standard Surface Dynamics (SD) profilometer has two tracking wheels to measure the height between the frame of the car and the pavement. That distance, which is sensed by a potentiometer, is one of the inputs used to obtain the road profile. Very rough sections tend to damage the potentiometers, which are connected to the tracking wheels. The trailing arm, to which the tracking wheels are connected, is held in contact with the road by a 300-pound force exerted through a torsion bar. The standard profilometer speed is 20 mph, at which speed the torsion bar tends to minimize the bouncing of the wheels. Speeds greater than about 20 mph produce excessive bouncing of the wheels, which distorts the profile measurements. The use of non-contact transducers in the profilometer would make it possible to increase the profilometer speed on rough surfaces without damaging the profilometer instruments.

Non-contact transducers have the following advantages.

(1) The speed of the profilometer can be increased to 50 mph or more. As noted above, the profilometer with the tracking wheel cannot operate faster than about 20 mph because of the bouncing wheel problem. The higher profiling speed is desirable on freeways with heavy traffic volumes, where the average running speed is usually above 50 mph and where it is prohibitively expensive to close a lane to make a profile measurement.

(2) Sections with high levels of roughness, which tend to damage the potentiometers in the standard profilometer layout, do not affect non-contact transducers.

(3) The high-frequency vertical accelerations transmitted by the trailing arms to the frame of the car when rough sections are profiled tend to overload the computer, causing high variation in the profile determination. These are not a problem with non-contact transducers.

DESCRIPTION OF THE DEVICES

A brief description of the devices and their functions is included here to provide a better understanding of the non-contact probes.

Laser Device

The laser transducer used in this experiment is produced by Selective Electronic Co. (SELCOM). The device is called optocator. It contains two pieces of hardware: the gauging probe and the central processing unit.

The gauging probe (see Fig 4.1) consists of

(1) a laser light source,
(2) a camera unit with lens and detector, and
(3) analog and digital processing electronics.

The central processing unit (CPU) (see Fig 4.2) has four principal functions:

(1) supplying the power,
(2) receiving data from the gauging probe,
(3) processing data from the gauging probe, and
(4) outputting data.

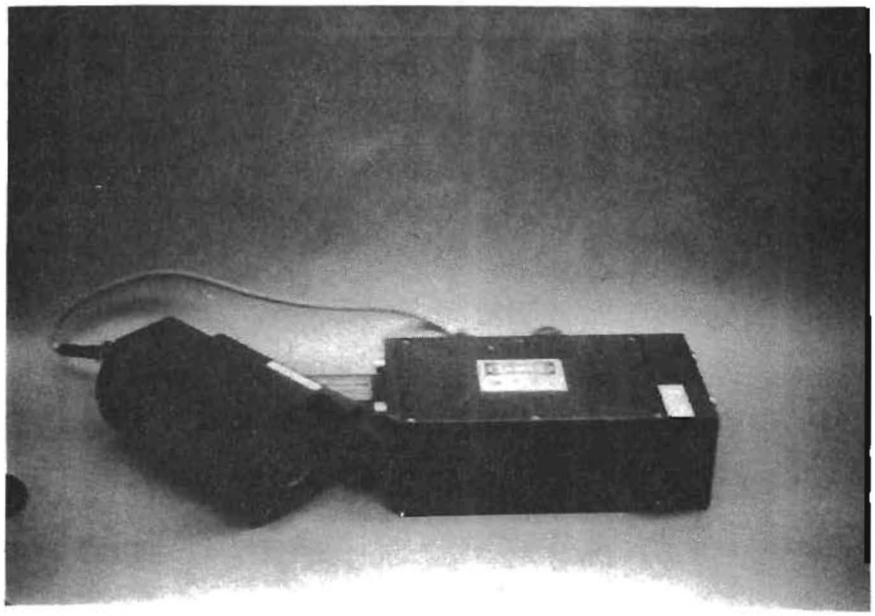

Fig 4.1. Laser gauging probe.

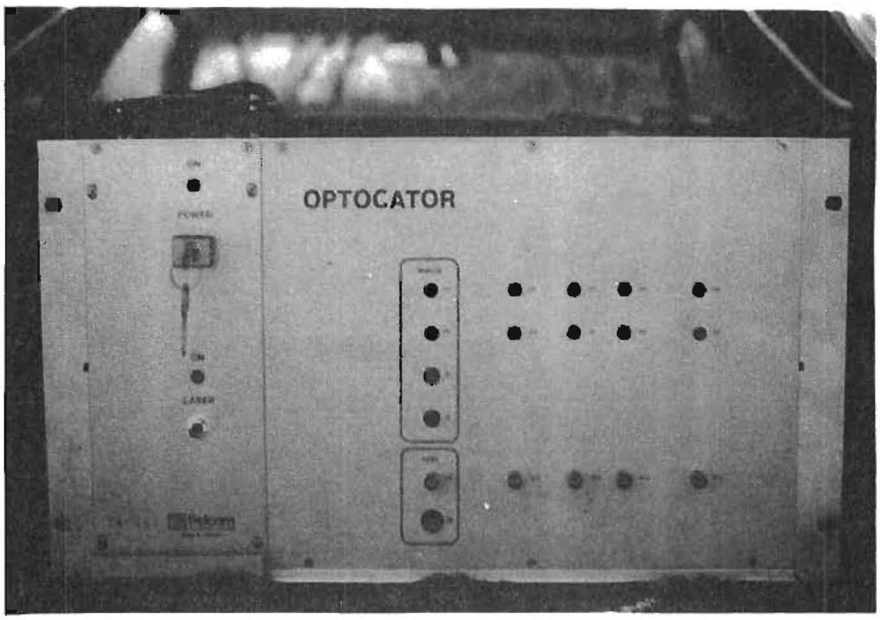

Fig 4.2. Laser central processing unit.

The recording of data is started when the laser light source produces an illuminated spot (3/8-inch by 1/8-inch) via a lens system onto the surface to be measured, creating direct and scattered reflected light. Part of the scattered light is projected to the photo sensitive detector in the camera (Fig 4.3). The image of the light spot on a photo diode element in the detector generates two currents, x_1 and x_2 (see Fig 4.4). The relation between these two currents givens the precise position of the center of the light image on the detector. This information is interpreted by the probe processing electronics, and sent via a connecting cable to the central processing unit.

The light source is controlled to maintain a constant intensity on the detector surface. This permits wide variation in the measured surface reflectivity-texture and color without affecting the measurement data. The light source is switched on and off 16,000 times per second; therefore, the system is not influenced significantly by ambient or background lighting. The output signal from the gauging probe is in either a digital or analog form.

Infrared Light Emitting Diode

A second non-contact device is an infrared-light linear transducer. The infrared light emitting diode (IRLED) application for measuring road surface profile was developed as a part of contract DOT-FH-11-8498 (System for Inventorying Road Surface Topography) between the FHWA and Southwest Research Institute (Ref 11).

The IRLED concept for height measurement illustrated in Fig 4.5 is very similar to that used with the Selcom device. The infrared LED projects a beam of energy downward normal to the pavement, illuminating a spot. Scattered energy from this illuminated spot is intercepted by the lens and focused on the dual-element detector. As shown in Fig 4.5, a change in road height causes a change in the position of the image on two electro-optical detector elements. The change in elevation of the road surface with respect to the elevation of the device is determined by comparing the electrical output from Detector 1 with that from Detector 2. In the initial position,

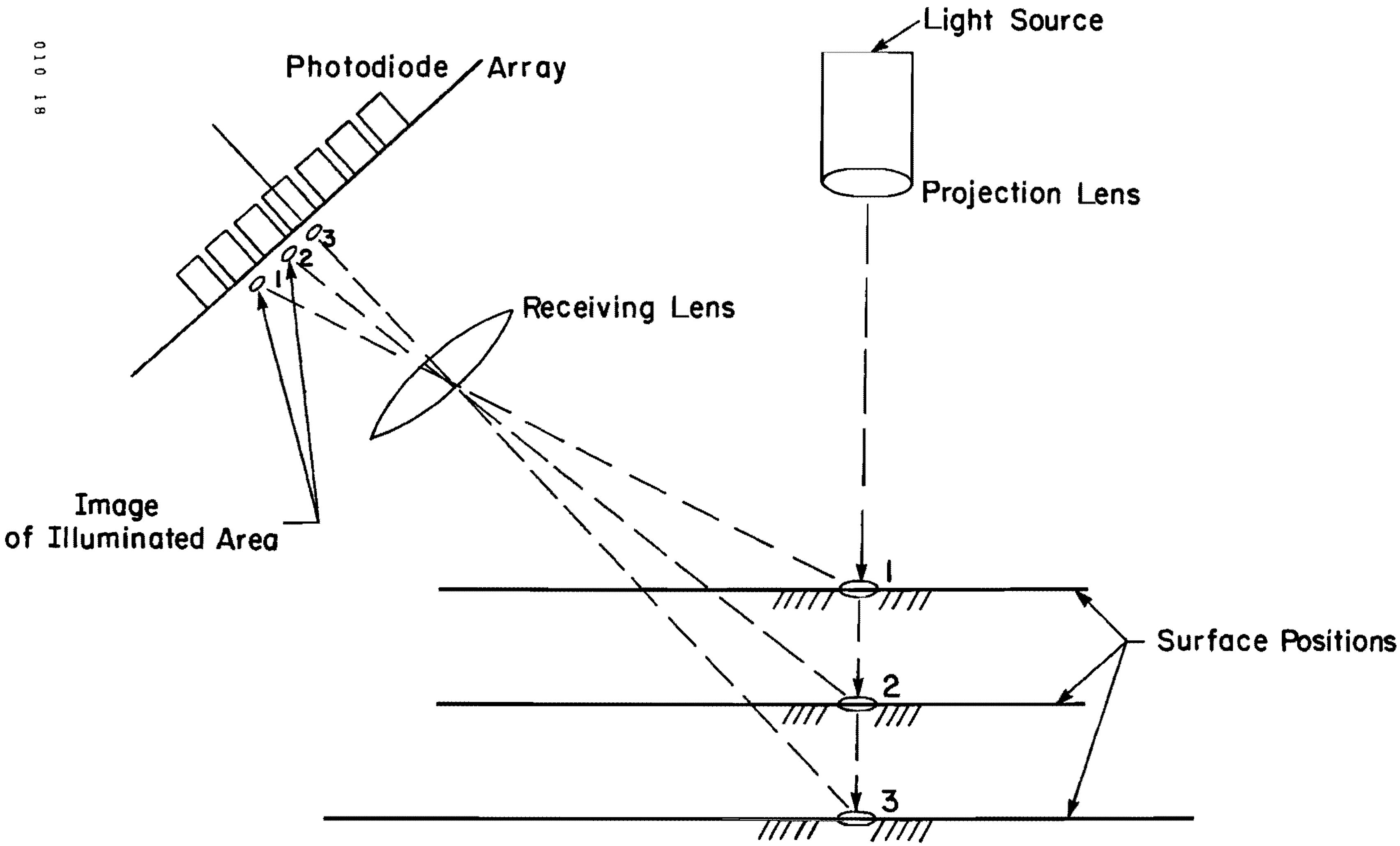

Fig 4.3. Basic laser light non-contact lens displacement transducer design.

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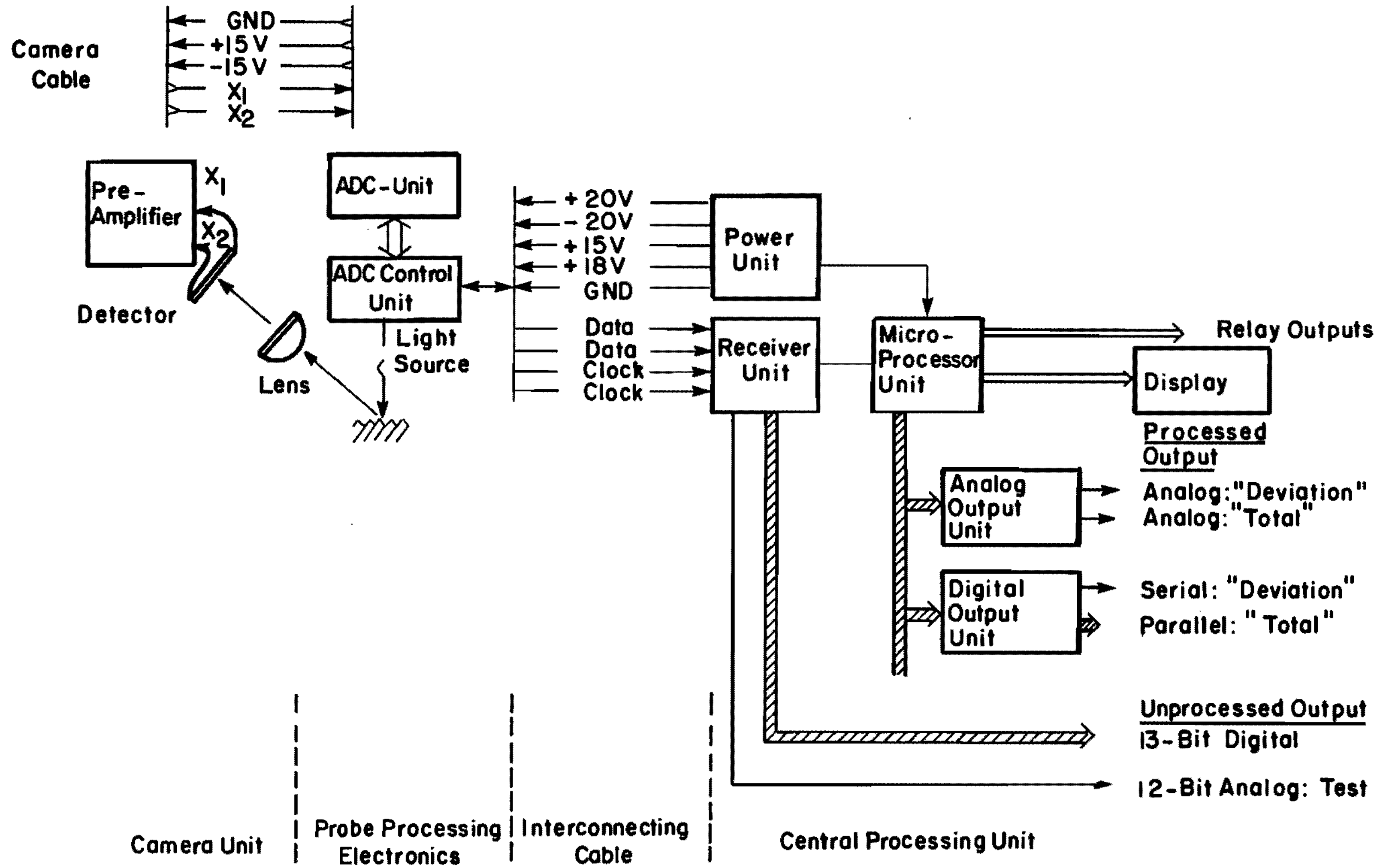

Fig 4.4. General functioning of SELCOM probe.

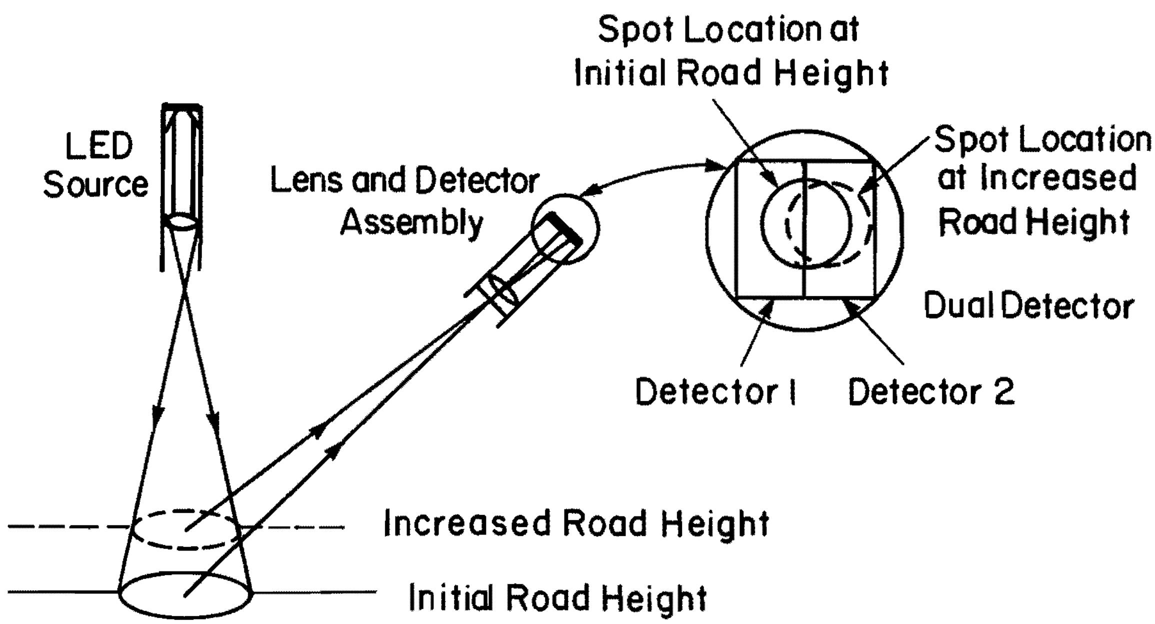

Fig 4.5. Optical height measuring technique (after Ref 11).

the image of the spot is centered on the two detectors, and thus the electrical output from both is the same. If the image moves so as to fall more on one detector than on the other, the outputs are no longer equal but they are proportionately different, depending upon the magnitude of the displacement. The difference in the electrical signals is proportional to the displacement and for small displacements it is nearly linear. For larger displacements the function is not linear but is proportional to the difference in the areas of the image on the two detectors.

Surfaces with non-uniform reflectance will produce a change in the average intensity of the portion of the spot image falling on each of the detectors, thereby causing variation in the electrical output that is similar to that produced by elevation changes. For example, if a white strip appeared only in the portion of the image that fell on one detector, then the output of that element would be abnormally high compared to the output from the other detector which viewed only the dark pavement. The solution to the problem was to use two photo detectors to sense the infrared spot in such a manner that the reflectance variation could be made to cancel when the outputs of the two photo detectors were fed into a summing amplifier. A geometry which accomplishes this result is shown in Fig 4.6. The infrared source is pointed perpendicular to the pavement surface with the two optical detectors placed at complementary angles on either side. The illuminated spot (4-inch diameter) in Fig 4.6 is depicted as being lower than the normal pavement height (simulating a depression); a dark area has been included within the spot to simulate the effects of non-uniform reflectance. Under these conditions, the image of the spot on each of the detectors produces height signals from the detectors which are of the same sense. However, since the detectors view the illuminated spot from opposite sides, the dark area within the spot appears on the upper half of Detector 1 and on the lower half of Detector 2. The effects of the non uniformity will be of opposite senses in the electrical output of the detectors and will therefore cancel when the outputs are summed.

The infrared transducer is self-contained in a heavy aluminum housing (see Figs 4.7 and 4.8). The infrared light is projected by means of a dual lens assembly which focuses it into a 4-inch-diameter spot on the pavement.

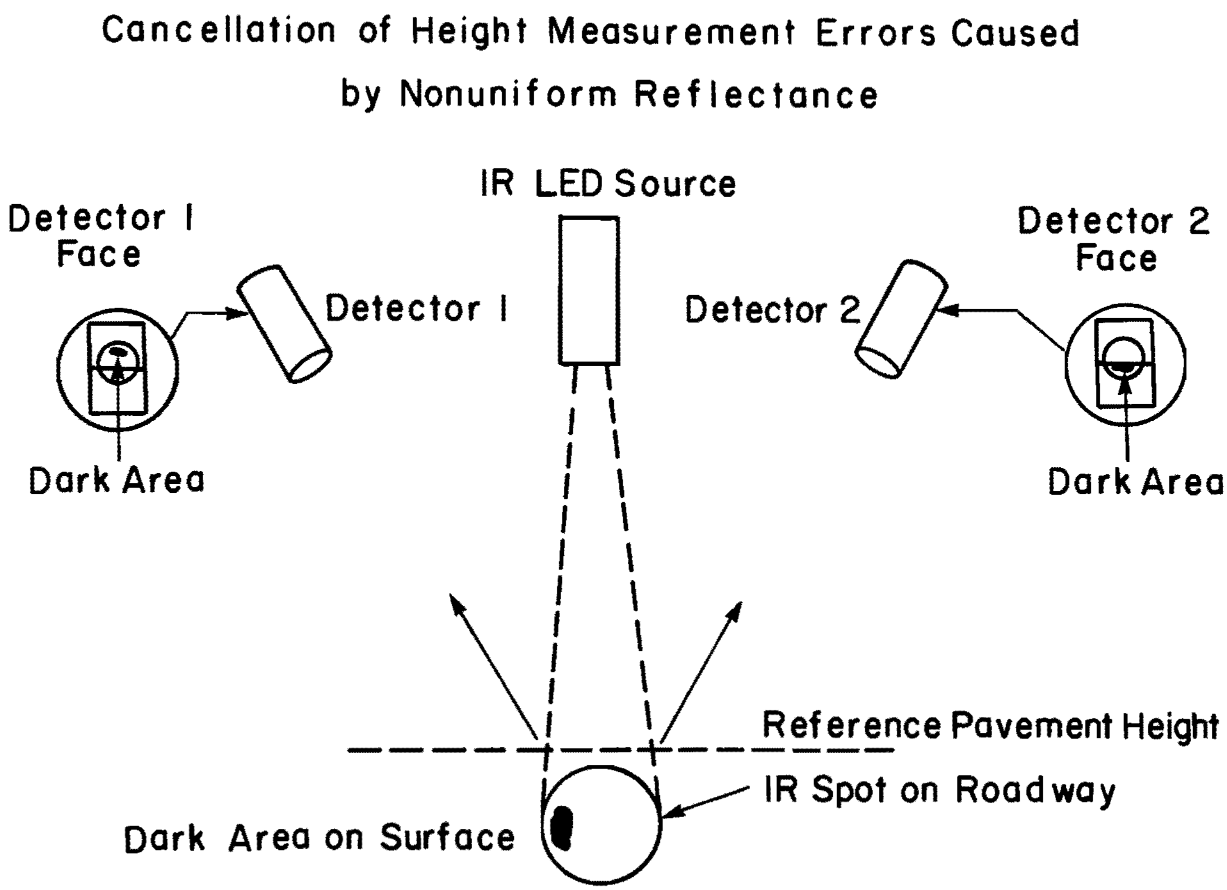

Fig 4.6. Dual detector concept for differential reflectance compensation (after Ref 11).

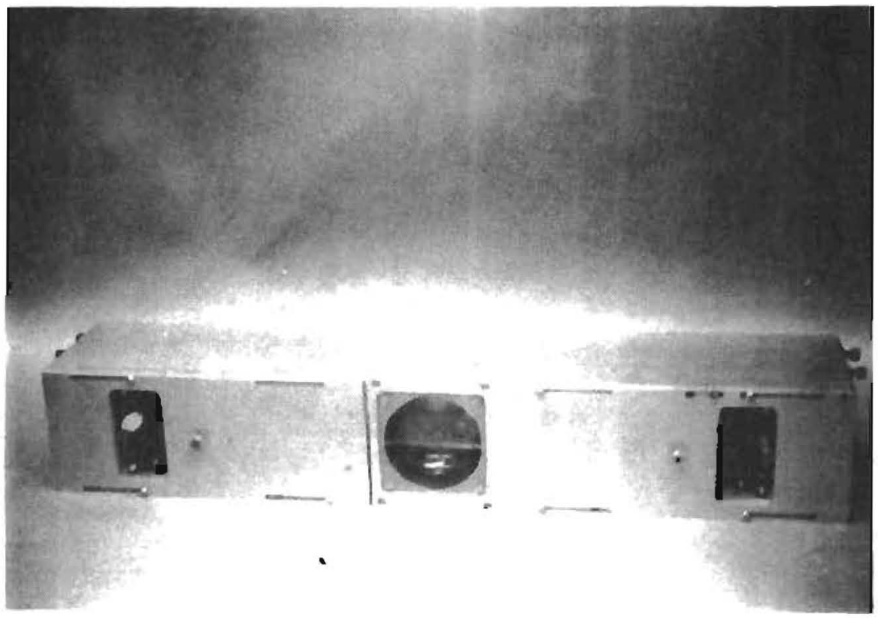

Fig 4.7. Front view of infrared transducer.

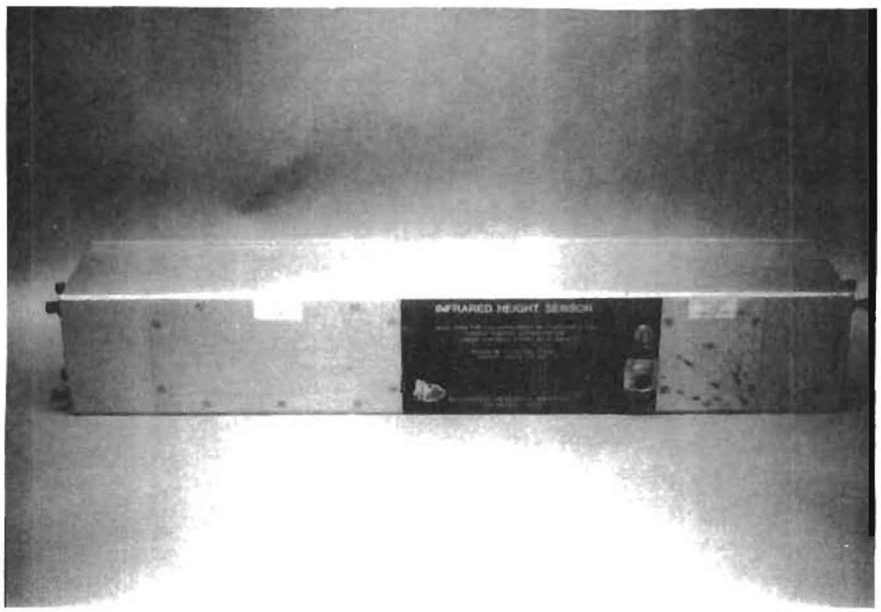

Fig 4.8. Back view of the infrared transducer.

The electronics required for amplifying and filtering the modulated output signal are included in this package.

K. J. LAW NON-CONTACT TRANSDUCER

Description of the Device

A brief description of the K. J. Law non-contact transducer is included here to provide a better understanding of its use.

The K. J. Law device uses a light source and a projection system for focusing a rectangular light beam on to a road surface. An optical receiver is spaced from the light source on the vehicle and receives an image of the rectangular beam diffusely reflected from the road surface (see Fig 4.9). The optical receiver is coupled to electronics for effectively measuring the distance between the frame of reference and the road as a function of the angle of incidence of the beam reflected onto the receiver. The optical receiver includes a rotating scanner comprising a plurality of plane reflective surfaces mounted in a circumferential array around the scanner axis of rotation (Fig 4.10). As the scanner rotates, each reflective surface in turn reflects the road image through a lens onto a photo detector. Thus, the angle of incidence of the reflected road image may be effectively determined as a function of the angle of rotation of the scanner at the moment at which the road image is reflected onto the photodetector (Fig 4.9). Each scanner facet reflects the reference beams successively through a lens onto the reference photodetector. The reference beams so reflected establish a measurement window corresponding to the respective angular positions of the scanner and within which the road image is received. The distance between the vehicle frame of reference and the road surface is then determined for each reflected road image within the measurement window. The K. J. Law device includes circuitry for processing the signals received from the photodetectors which are indicative of the road and reference image, determining the temporal relationship therebetween, i.e., the time position

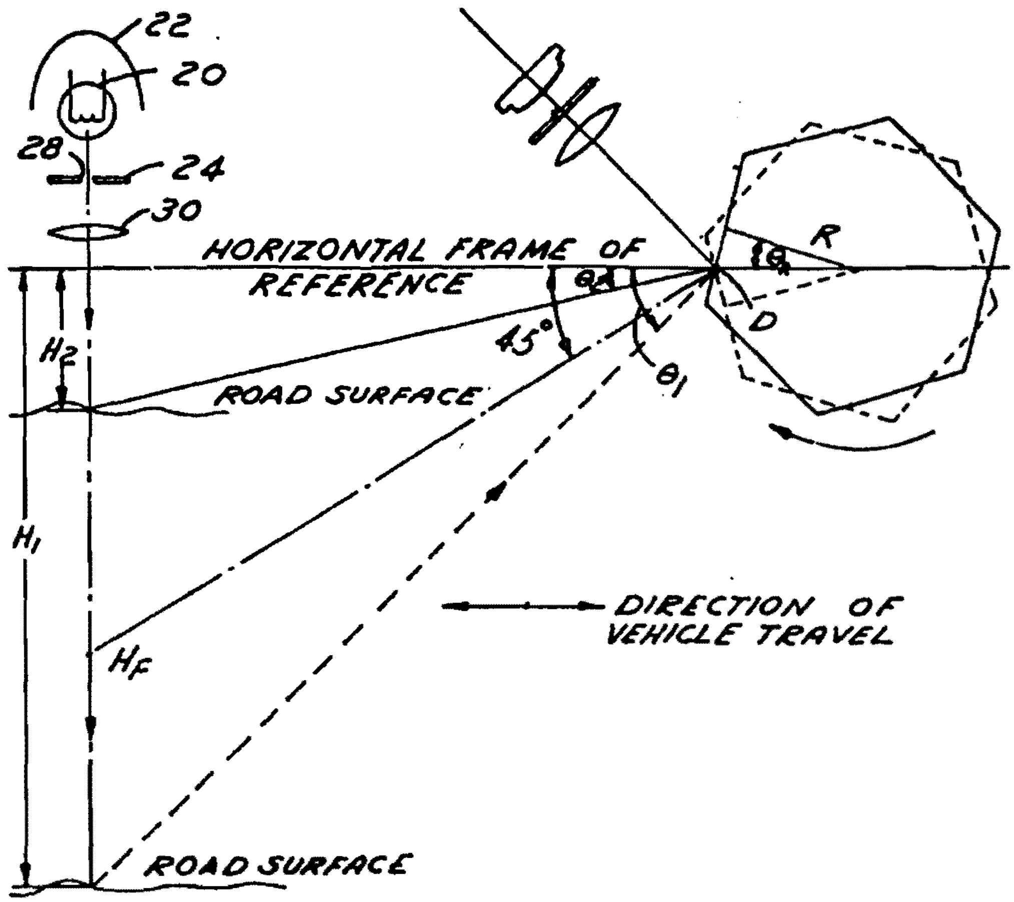

Fig 4.9. Schematic diagram of the road image optics portion.

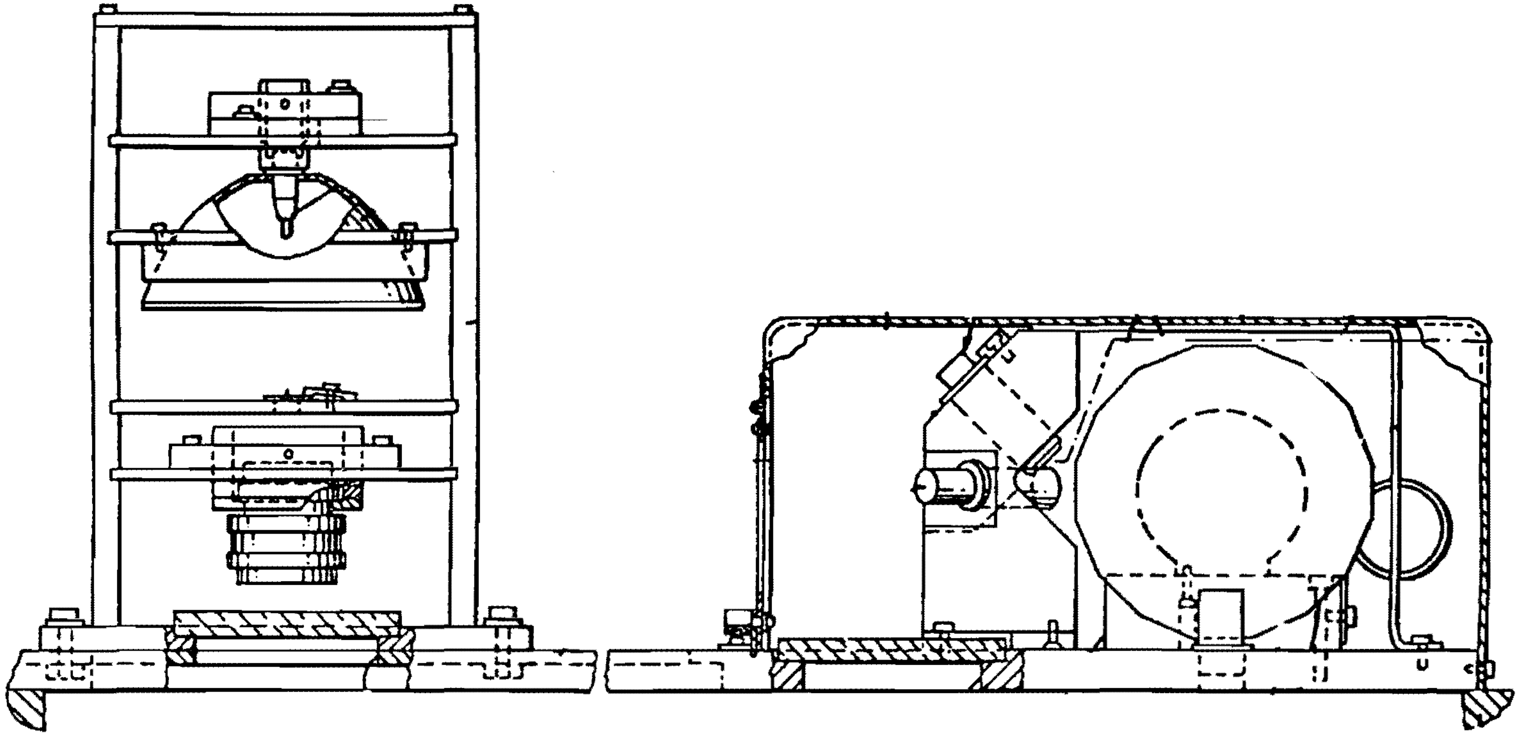

Fig 4.10. A fragmentary, partially sectioned diagram of the light tower and the optical receiver.

of the road image within the reference measurement window, and the calculated distance to the road surface.

The light tower, the optical receiver, and the processing unit are shown in Figs 4.11, 4.12, and 4.13, respectively.

BENCH CALIBRATION OF THE TRANSDUCERS

A series of bench calibration tests were conducted on the transducers to determine the linearity, sensitivity, capability to indicate average height surface, and height variation within the area of the illuminated spot. The sensitivity, in terms of the voltage output per unit change in height was measured for each device.

Laser Device (SELCOM)

In order to determine the relationship between output voltage versus height to the target, the SELCOM device was mounted on a bench, as shown in Fig 4.14. A mobile target was placed under the device, and its position was measured in 0.10-inch units. The analog output signal which was obtained from the central processing unit was measured by a digital voltmeter with a sensitivity of 0.001 volt. After the device was installed on the bench, it was essential to find the measurement range of the gauging probe. This was done by pointing the light beam at the target and moving the target along the axis of the light. When the target was outside the measurement range the indicator lamp was lit on the CPU. As soon as the target was moved inside the measurement range the indicator lamp went off. The range for the device was determined to be 8.8 to 13.8 inches, as measured from the light source.

Finally the relationship between output voltage and height was obtained by moving the target vertically in 0.1-inch increments and recording the respective voltage readings. A linear regression analysis was performed with the data obtained. The corresponding regression equation is

$$Y = -.0410 + 0.948 x_1 \qquad R^2 = 0.9997 \qquad (4.1)$$

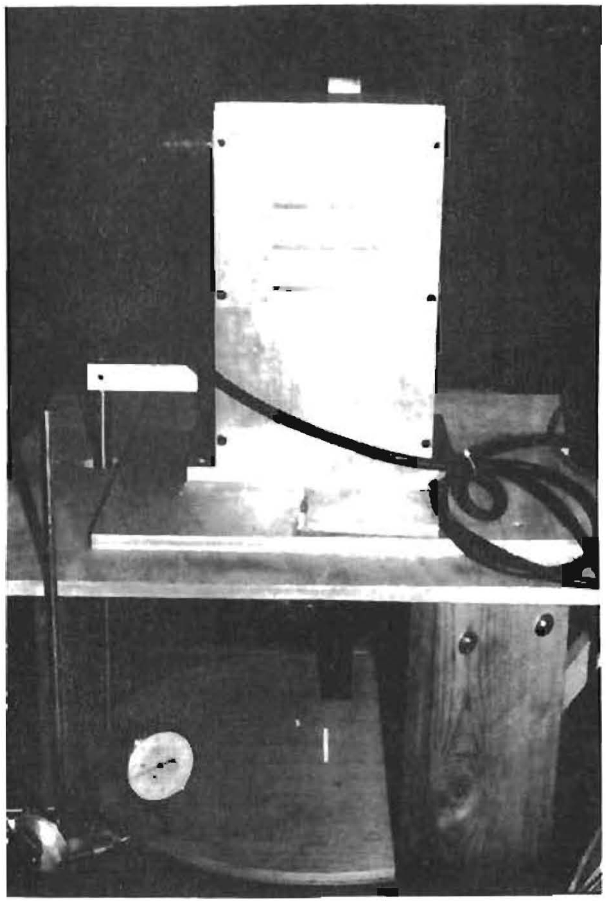

Fig 4.11. Tower of light emission.

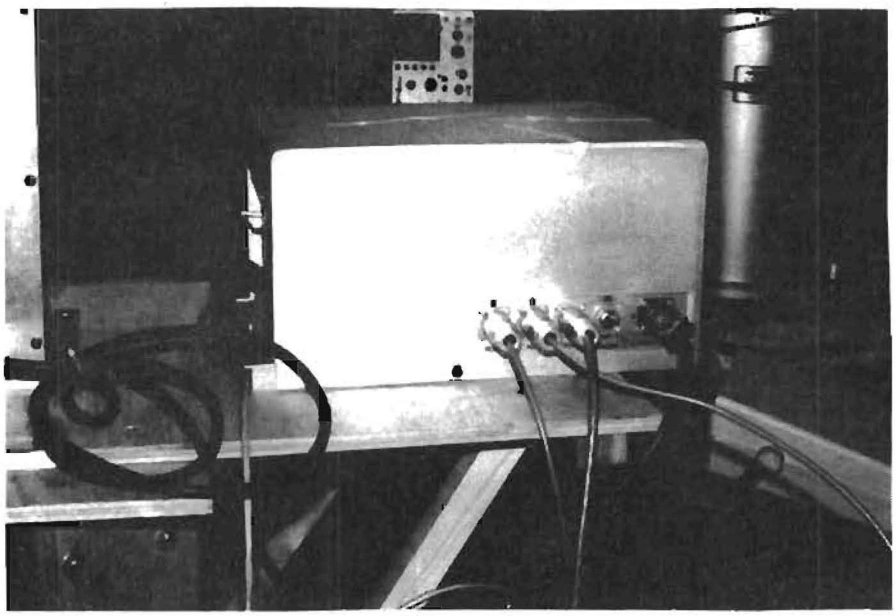

Fig 4.12. Optical receiver which uses rotating mirrors.

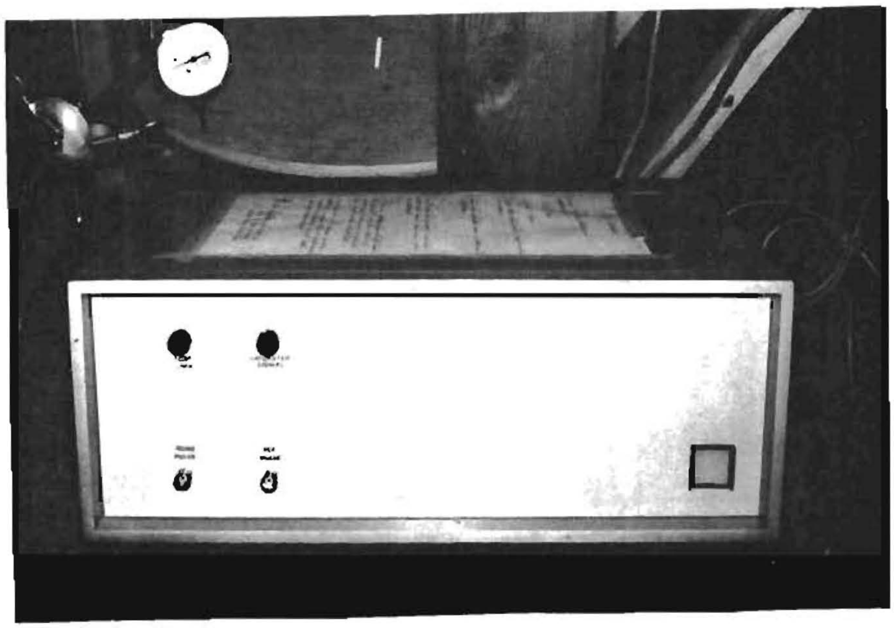

Fig 4.13. Processing unit.

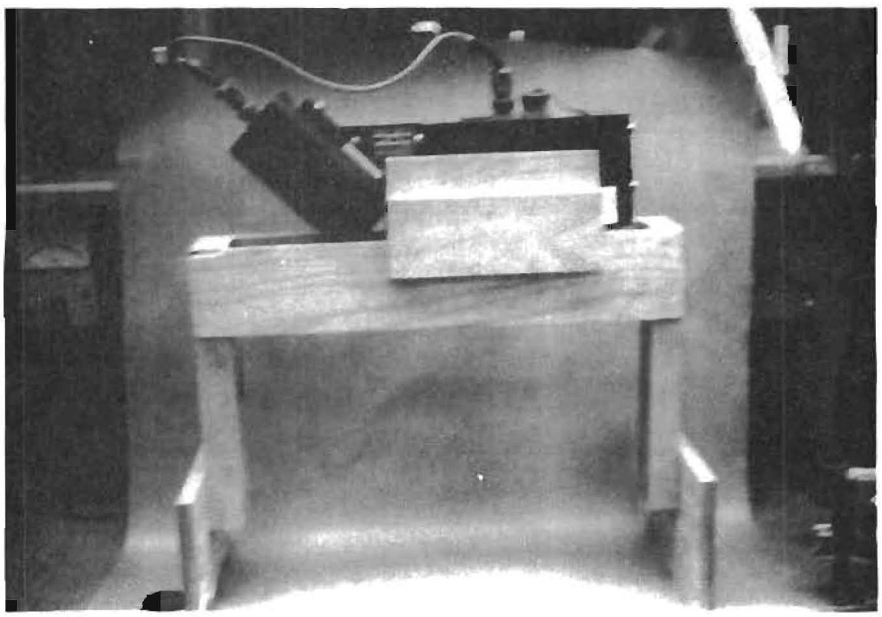

Fig 4.14. Mounting of SELCOM unit for bench calibration.

where

Y = voltage and

x_1 = distance between target and light source.

The equation which results from forcing the regression line through the origin is

$$Y = 0.936 x_1 \tag{4.2}$$

Figure 4.15 shows all the data points and the best fit line through the origin corresponding to the above equation. It can be observed that the regression coefficient (R^2) is very high, showing a very good linear correlation.

Infrared Transducer

The infrared transducer was mounted on the bench in a way similar to that of the SELCOM device, in accordance with the recommendations of Southwest Research Institute (SRI). The initial distance between the light source and the target was set at 14 inches. The working range of the device was found to be ± 2.5 inches with respect to that position. Figure 4.16 shows the arrangement of the device on the calibration bench.

The target was moved up and down in increments of 0.1 inch, for which voltmeter readings of the output signal were recorded. The initial calibration of the device resulted in a pronounced s-shaped curve (Fig 4.17). In order to verify this anomaly SRI realigned the device. Then, it was calibrated again and a final correlation was obtained. A linear regression analysis was performed on the data; and the corresponding equation is:

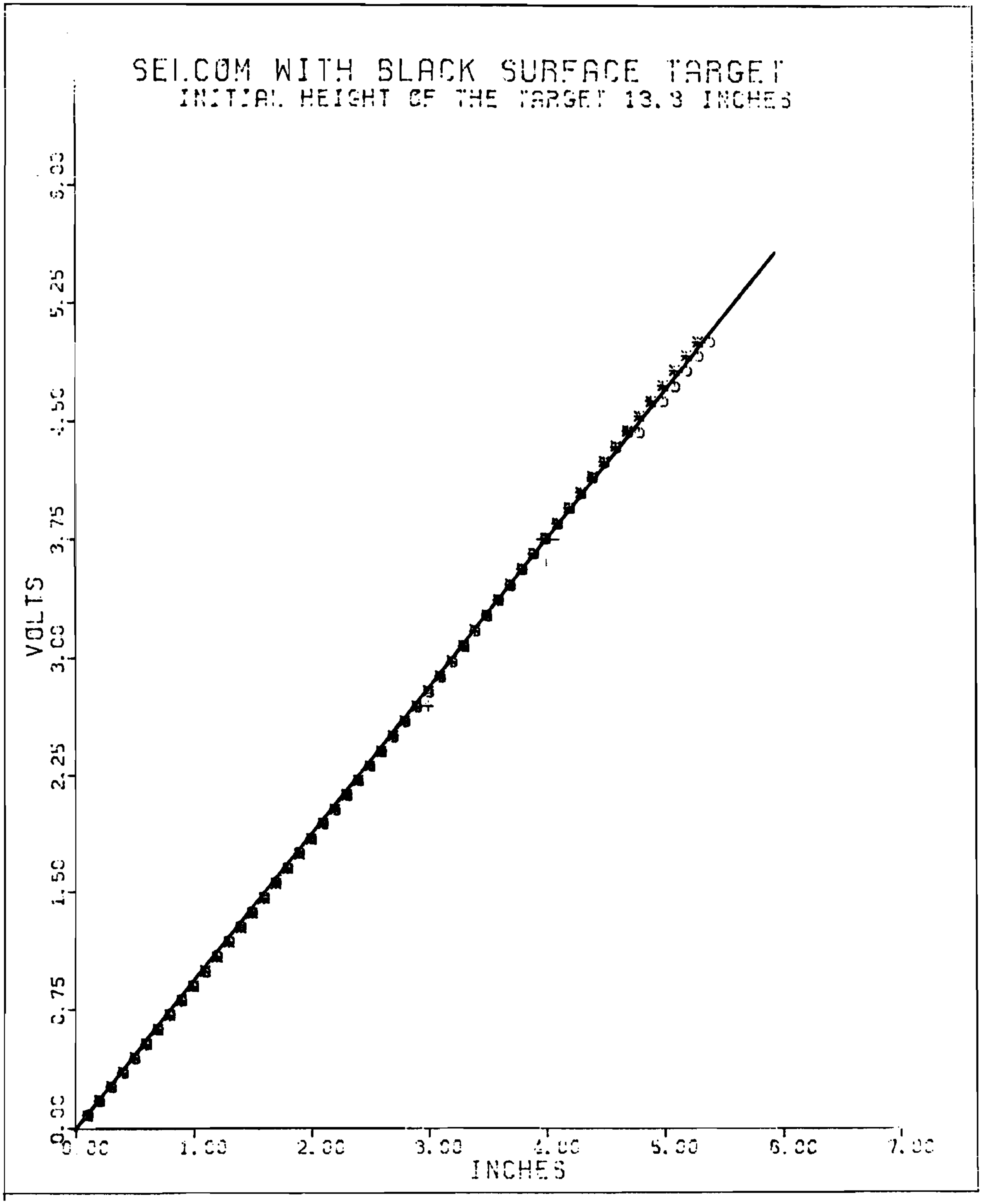

Fig 4.15. Data from Selcom unit and linear regression line of best fit.

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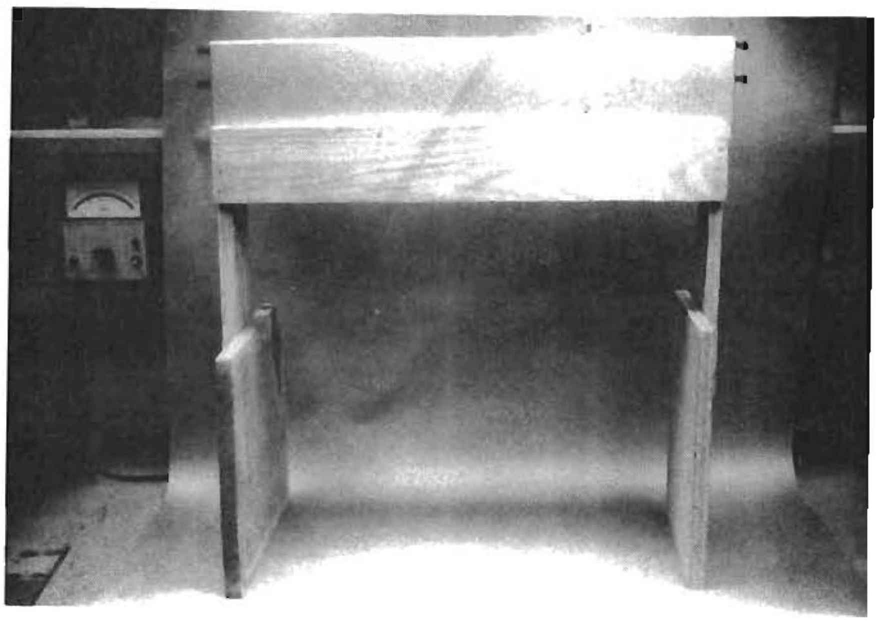

Fig 4.16. Mounting of infrared unit for bench calibration.

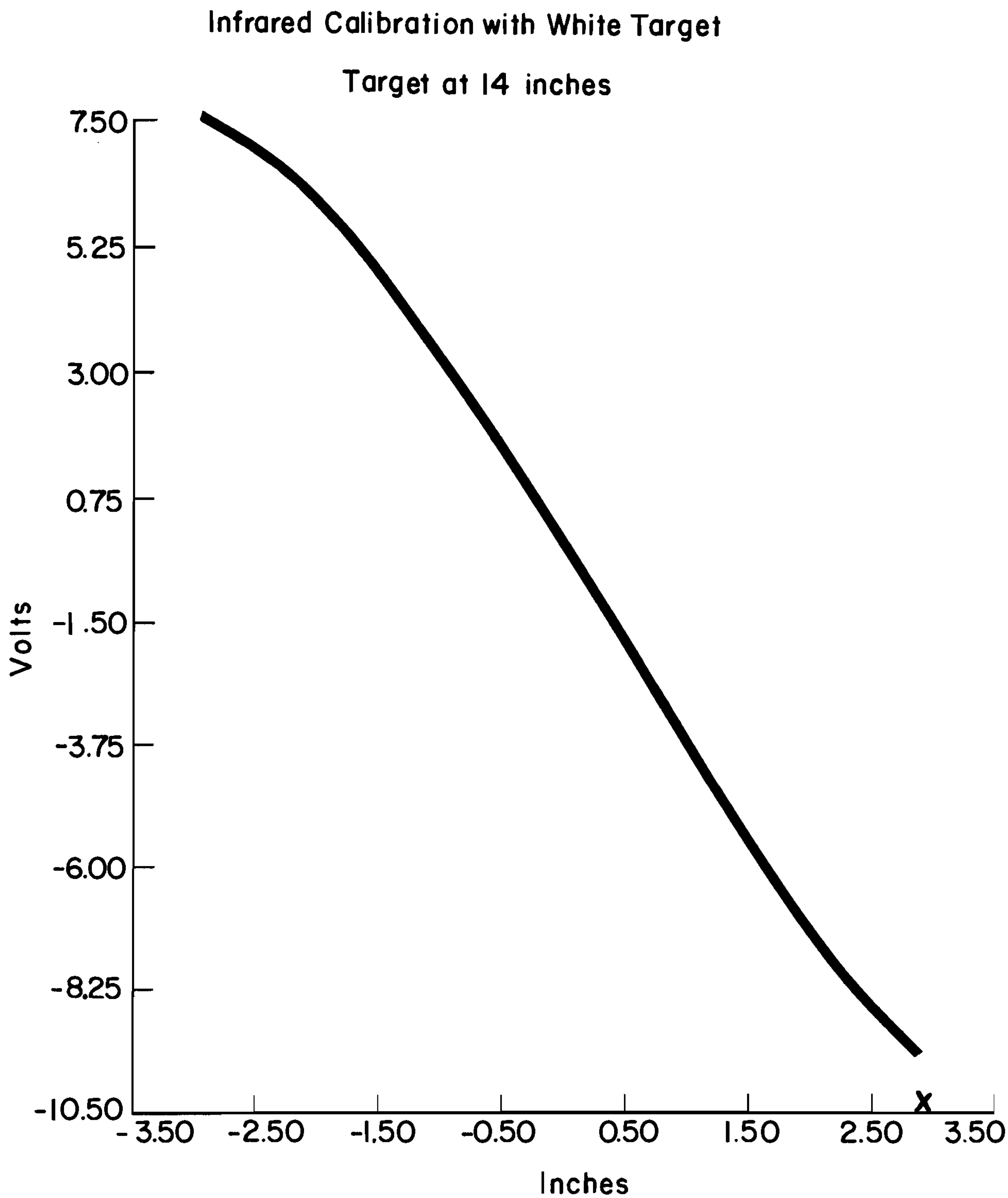

Fig 4.17. Data from initial calibration of infrared device.

$$Y = -0.368 - 3.01\,x \qquad R^2 = 0.994 \qquad (4.3)$$

where

Y	=	voltage and
x	=	distance between target and light source.

The regression line forced through the origin is

$$Y = -3.01\,x \qquad (4.4)$$

Figure 4.18 shows the final calibration data for the infrared device. The repeatability of the device is very good as is shown in Fig 4.18. A linear regression was used because it was more convenient ($R^2 = 0.994$). A curvilinear regression is also possible to use in this case.

K. J. Law Device

In order to obtain the relationship between output voltage versus target height, the K. J. Law transducer was mounted on a bench, as shown in Fig 4.19. A mobile target with the sensitivity required to measure a 0.06-inch vertical displacement was placed under the device. The analog output signal was obtained from the processing unit. This analog signal was then measured by a voltmeter with a sensitivity of 0.001 volt for each respective position.

After the device was installed on the calibration bench, it was essential to find the measurement range of the probe. This was done by moving the target from the maximum (0.0 volts) to the minimum (-12.87 volts)

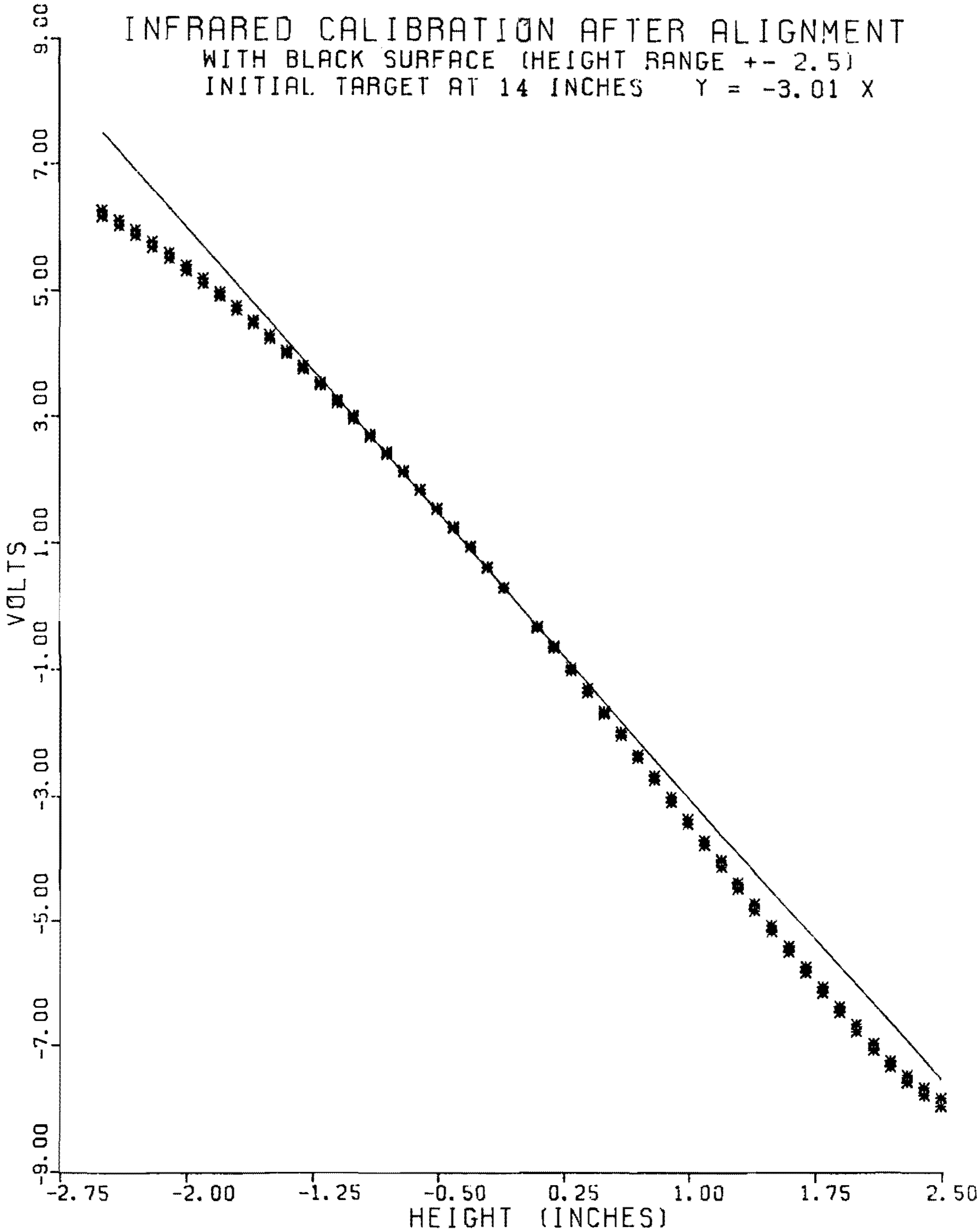

Fig 4.18. Infrared final calibration curve.

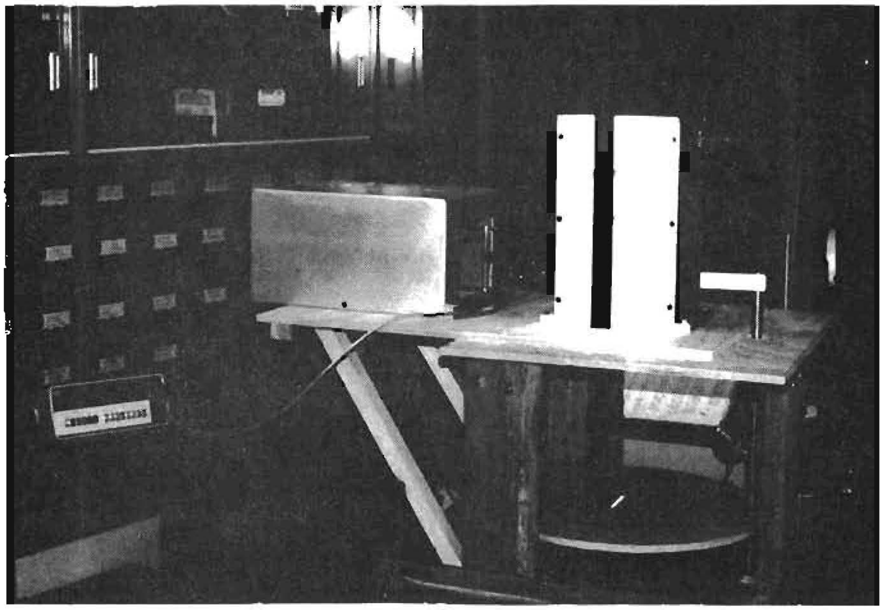

Fig 4.19. K. J. Law non-contact transducer mounted on the calibration bench.

output voltage. The distance range for this device was found to be between 9.0 and 14.7 inches, measured from the light source.

Finally, the relationship for output voltage versus target height was obtained by moving the target in 0.06-inch increments and recording the voltage reading. A linear regression analysis was performed with the data obtained.

The corresponding equation is

$$y = 0.105 + 0.437\ x_1 \qquad (4.5)$$

$$R^2 = 0.996$$

where

y = distance between target and light source, inches, and
x_1 = voltage, volts.

Forcing a straight regression line through the origin, the equation is

$$y = 0.425\ x_1 \qquad (4.6)$$

Figure 4.20 shows all the data points and the best fit line corresponding to Eq 4.5. It can be observed that a linear regression between voltage and height, explains a large part of the relationship ($R^2 = 0.996$). The repeatability of the measurements was very good as is shown in Fig 4.20.

MOUNTING THE TRANSDUCERS FOR OPERATION IN THE PROFILOMETER

The surface dynamics profilometer device is described in detail in Refs 1 and 12. A brief description of the profilometer is included in Chapter 2.

For the research described herein the tracking wheel and the potentiometer were replaced by non-contact transducers which perform the same function, i.e., measure the distance between the frame of the vehicle and the

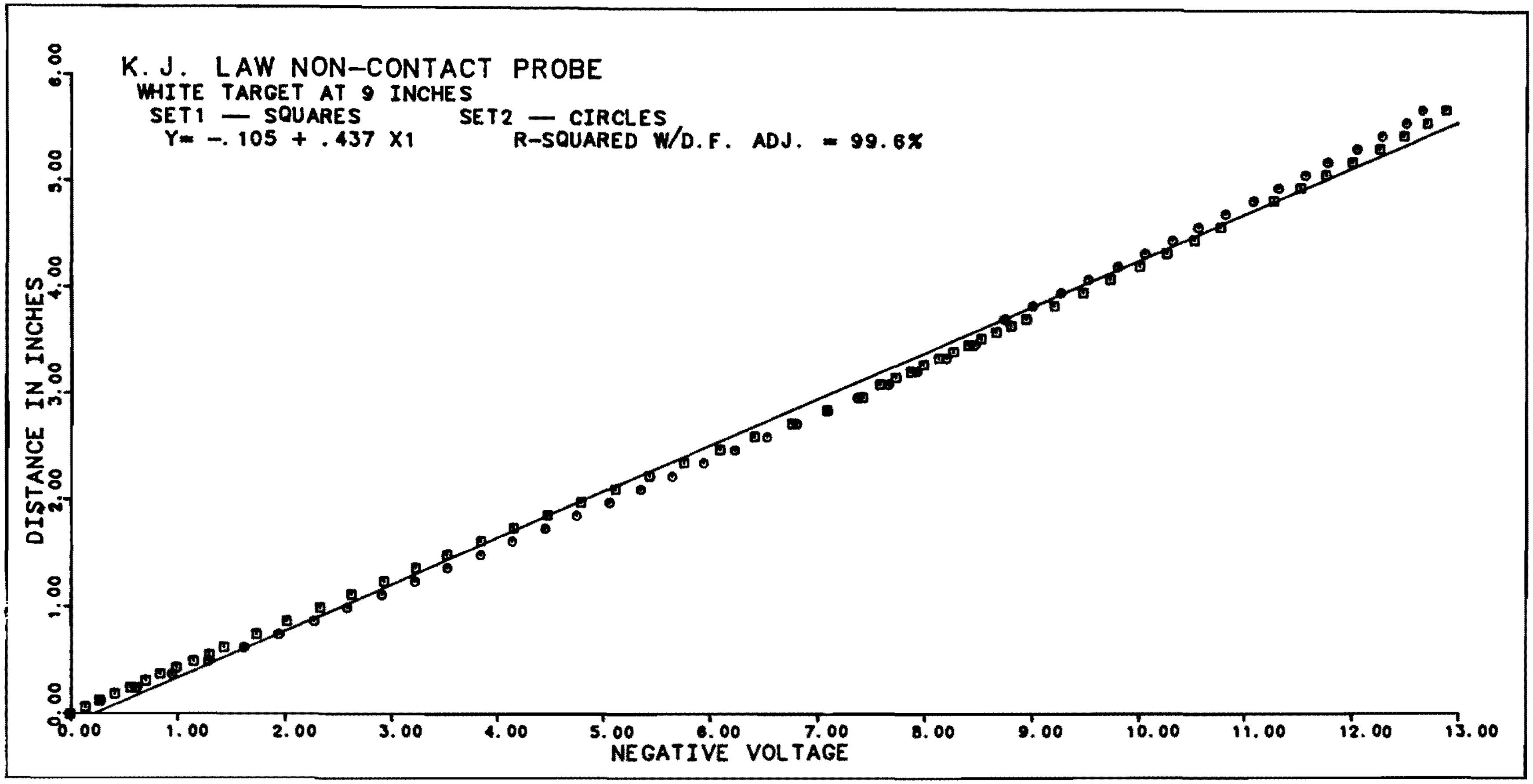

Fig 4.20. Distance vs. Voltage.

pavement surface. The analog signal from these devices was transmitted to the computer in the profilometer to obtain the road profile.

Figure 4.21 shows the position of the non-contact probe, which was mounted in the front part of the profilometer van just behind the right front wheel. The accelerometer was mounted directly above the non-contact transducer in order to have the measured displacements along the same vertical axis. After all the instruments were connected according to the standard procedure, a self-calibration of the non-contact device was performed using one-inch steps. This procedure gives the scaling factor to the computer program for the profile computations using the analog output signal from the non-contact device.

Figure 4.22 shows the mounting of the SELCOM device on the van. In the current research only one wheel path was profiled (the right wheel path) at a time, because only one non-contact device could be mounted at a time in the profilometer.

FACTORIAL EXPERIMENT

In order to evaluate both non-contact probes, six flexible pavement sections from among the 30 test sections in the Austin area were chosen with three levels of Serviceability Index (SI). The SI was measured with the old profilometer (January 1984) running at 20 mph. The sections are

Section 6	SI = 2.36	Level I
Section 2	SI = 2.48	Low
Section 5	SI = 3.41	Level II
Section 9	SI = 3.06	Medium
Section 7	SI = 4.75	Level III
Section 32	SI = 4.41	High

The sections were then profiled eight times each at two different speeds (35 and 50 mph) with each non-contact probe. The order of the runs for each section was selected randomly and the number of runs was selected according to statistical sample-size theory. From the initial measurements the following parameters were selected by using the root-mean-square vertical

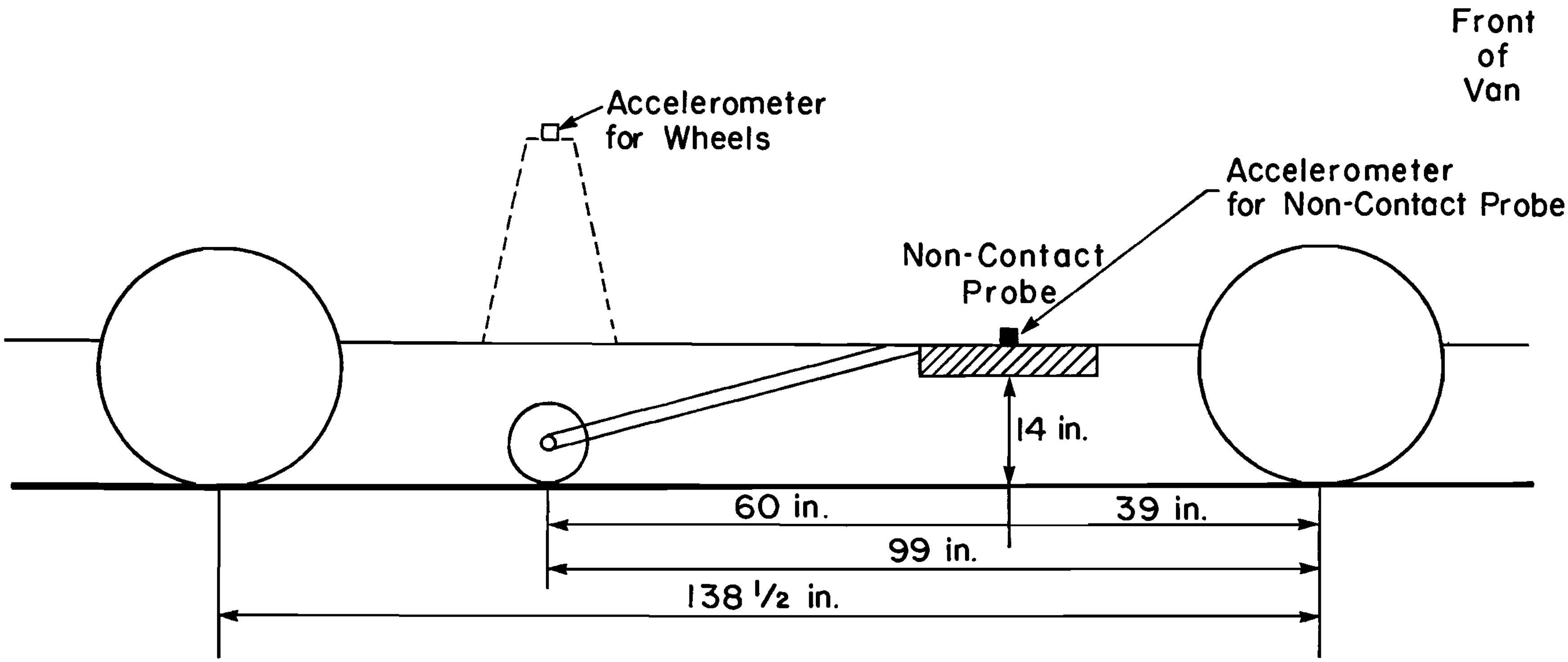

Fig 4.21. Sketch of position of the non-contact device in the profilometer.

Fig 4.22. SELCOM device mounted under the profilometer vehicle.

acceleration (RMSVA) for the 0.5-foot base length as an indicator of the variability in profilometer performance.

$$\delta = \mu_2 - \mu_1 = 10$$

$$\sigma = 5.0$$

where

δ = difference between the mean of the two populations, and

σ = standard deviation of the RMSVA value at 0.5-foot base length.

$$D = \frac{\delta}{\sigma} - 2.0$$

using the following values:

α = 0.05 double-sided test,
β = 0.05,
α = probability of a Type I error, and
β = probability of a Type II error;

the appropriate sample size was found using the technique described in Ref 14:

$$n = 8 \text{ runs.}$$

In order to make a thorough evaluation of the ability of the two non-contact probes to function in the profilometer to produce data for computing the Serviceability Index that would be consistent with values from the standard profilometer equipped with road-following wheels, a full factorial experiment was designed. In Table 4.1, the full factorial is shown; in it 8 samples were taken per cell. This factorial was repeated 9 times, one for each RMSVA base length. The standard profilometer (with tracking wheels) was also included in the experiment, with two wavelength filters: a 200-foot-wavelength filter (tracking wheels 1) and a 300-foot-wavelength filter (tracking wheels 2).

RESULTS OF THE EXPERIMENT

Profiling of the selected sections was done with the SELCOM, the infrared device, and the standard profilometer during the period of January through April 1984. Every set of profile data was analyzed using RMSVA as a summary statistic. The RMSVA values were calculated for each of the 9 selected base lengths (0.5, 1.0, 2.0, 4.0, 8.0, 16.0, 32.0, 64.0, and 128.0 feet). A description of this parameter is presented in Chapter 2. Using the RMSVA as an indicator, a series of comparisons was performed for the different road sections.

RMSVA Coefficient of Variation

This parameter was used as an expression of the repeatability of the instruments when they are used in the same wheel path and on the same section. These variables were calculated for each base length and for each instrument.

RMSVA Coefficient of Variation of the Non-Contact Transducers

In Tables 4.2 and 4.3 the values of the coefficient of variation in percentage (percent CV) are shown for the laser and the infrared device, respectively. An inspection of these tables shows that CV values are generally closer to 5 percent or less, except for section 9 for the laser device and section 7 for the infrared device. It is important to emphasize that the desired wheel path was not marked on the pavement for the driver of

TABLE 4.1. FULL FACTORIAL EXPERIMENT DESIGN FOR COMPARING THREE DISPLACEMENT-MEASURING DEVICES.

				SI Level					
				Level I SI = 2.4		Level II SI = 3.8		Level III SI = 4.8	
Device	Wave Length Filter (WLF)	Speed (MPH)	Wheelpath (W/P)	Section 2	Section 6	Section 5	Section 9	Section 7	Section 32
Selcom	200	35	Right	8	8	8	8	8	8
Selcom	200	50	Right	8	8	8	8	8	8
Infrared	200	35	Right	8	8	8	8	8	8
Infrared	200	50	Right	8	8	8	8	8	8
Tracking Wheels 1	200	20	Right	8	8	8	8	8	8
Tracking Wheels 1	200	20	Left	8	8	8	8	8	8
Tracking Wheels 2	300	20	Right	8	8	8	8	8	8
Tracking Wheels 2	300	20	Left	8	8	8	8	8	8

TABLE 4.2 SELCOM RMSVA COEFFICIENT OF VARIATION

			Base Length (in feet)									
Section	Wheel Path	Speed MPH	0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	35	2.9	4.81	2.86	2.65	1.32	0.95	1.84	4.3	11.8	2.36
		50	4.87	6.56	3.14	2.64	1.70	1.46	2.31	3.5	8.6	
2	R	35	3.5	3.3	3.06	1.7	3.5	3.6	4.05	5.9	6.29	2.48
		50	1.9	1.13	2.50	2.6	4.1	3.5	2.99	6.1	4.49	
5	R	35	2.4	2.96	2.49	3.2	1.6	2.79	3.24	6.68	21.85	3.41
		50	2.9	2.07	2.59	2.5	3.12	2.91	4.35	6.68	30.16	
9	R	35	1.41	22.5	16.95	7.6	4.45	2.38	4.8	6.8	19.7	3.06
		50	3.3	2.55	2.23	1.37	1.71	1.57	2.56	3.1	17.9	
7	R	35	3.7	4.49	2.93	3.3	1.93	1.42	3.36	5.6	0.0	4.75
		50	3.17	2.66	2.61	1.73	2.00	1.92	2.34	0.0	18.8	
32	R	35	4.4	5.23	4.0	3.19	1.26	2.5	5.06	5.19	5.15	4.41
		50	6.4	4.40	2.9	1.65	1.82	2.16	3.10	4.30	6.85	

R = Right   L = Left

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TABLE 4.3 INFRARED RMSVA COEFFICIENT OF VARIATION

Section	Wheel Path	Speed MPH	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	35	3.5	1.99	3.30	4.9	6.2	8.4	6.2	6.0	0.8	2.36
		50	2.5	3.80	4.30	6.3	7.9	10.3	6.8	5.9	8.58	
2	R	35	3.89	4.27	5.06	4.69	3.98	1.33	1.89	2.09	4.49	2.48
		50	4.68	6.66	6.37	6.60	6.63	5.31	1.82	3.05	0.0	
5	R	35	1.3	2.5	1.8	2.0	1.90	2.6	3.10	4.30	16.6	3.41
		50	2.5	1.8	2.3	2.10	2.10	1.4	3.30	6.70	16.6	
9	R	35	4.80	5.23	3.17	2.04	1.36	1.61	1.65	4.96	0.0	3.06
		50	3.70	2.11	1.65	0.96	1.74	1.45	1.48	4.61	0.0	
7	R	35	14.0	10.5	10.9	8.0	5.0	2.4	4.8	5.6	0.0	4.75
		50	13.5	10.9	14.3	12.6	7.9	4.0	0.0	0.0	0.0	
32	R	35	3.37	3.98	1.37	1.38	1.53	1.49	2.01	3.05	7.8	4.41
		50	1.20	2.66	1.83	2.49	1.50	1.33	1.35	3.05	5.14	

R = Right L = Left

the profilometer to follow; therefore, variability in the actual wheel path that was followed could account for of this variation. (The lanes were not marked to approximate real profiling conditions.) A series of plots was developed for coefficient of variation versus base length for each combination of section, speed, and device. These plots are included in Appendix B.

When the CV values for both speeds are compared, it can be seen that the infrared device at 35 mph has lower values of CV than at 50 mph. On the other hand the laser (SELCOM) device has lower values of CV at 50 mph than at 35 mph. The infrared device thus provides better repeatability at 35 mph, and the laser device (SELCOM) at 50 mph. In Table 4.4 a summary of the CV differences for both speeds is shown.

RMSVA Coefficient of Variation of the Standard Profilometer (Wheels)

Tables 4.5 and 4.6 show the CV values for the standard profilometer with a 200 wavelength filter and a 300 wavelength filter, respectively. From an inspection of these tables, it can be concluded that the CV values are generally less than 4.0 percent with the exception of section 39, which is a very rough section (SIV = 1.0). That section was evaluated in order to have additional information on the CV for very rough sections. If the CV values for the different wavelength filters are compared it can be seen that the standard profilometer with the 200-foot-wavelength filter has lower CV values than the standard profilometer with the 300-foot-wavelength filter. Therefore the profilometer with 200-foot-wavelength filter provides better repeatability. A series of plots of CV versus base length are included in Appendix B.

MEAN OF RMSVA VALUES

The mean of RMSVA values was calculated for each section and for each base length. Plots of mean RMSVA versus base length for all the sections are shown in Appendix C.

TABLE 4.4 COMPARISON OF CV FOR BOTH TRANSDUCERS

Speed	CV Infrared > CV Selcom	CV Infrared = CV Selcom	CV Infrared < CV Selcom
35 mph	Sections 2, 6, and 7	Sections 5 and 32	Section 9
50 mph	Sections 6 and 7	Sections 2 and 5	Sections 9 and 32

TABLE 4.5 RMSVA CV PERCENT FOR THE STANDARD PROFILOMETER WITH 200 WL

Section	Wheel Path	Speed MPH	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	20	3.5	2.7	2.9	3.4	2.2	2.6	2.4	4.1	0.0	2.36
	L	20	3.4	4.6	2.9	1.9	1.2	1.1	0.9	2.7	0.0	
2	R	20	2.06	2.66	2.44	1.81	2.36	1.52	1.48	4.12	0.0	2.48
	L	20	3.57	2.70	1.60	2.07	1.47	2.07	2.14	4.31	9.14	
5	R	20	4.3	2.9	2.3	2.5	3.1	3.4	3.3	5.1	31.04	3.41
	L	20	2.1	1.9	2.5	1.4	1.6	2.1	3.6	0.0	0.0	
9	R	20	2.16	2.22	2.14	1.72	1.12	2.00	1.70	2.98	0.0	3.06
	L	20	4.14	3.03	1.79	2.76	2.58	2.13	4.24	5.61	0.0	
7	R	20	2.20	1.56	2.13	2.46	1.24	1.91	0.0	6.79	0.0	4.75
	L	20	3.54	3.24	3.47	1.98	1.08	0.0	0.0	0.0	0.0	
32	R	20	3.34	2.76	2.58	1.28	1.41	1.43	2.45	0.0	0.0	4.41
	L	20	6.24	4.14	2.53	2.51	2.89	2.91	2.21	4.42	0.0	
39	R	20	12.99	8.6	7.65	1.50	1.45	2.10	2.76	3.77	0.0	1.00
	L	20	16.3	11.1	2.15	4.10	1.59	5.06	2.04	3.18	2.17	

R = Right L = Left

TABLE 4.6 RMSVA CV PERCENT FOR THE STANDARD PROFILOMETER WITH 300 WLF

Section	Wheel Path	Speed MPH	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	20	4.3	3.0	3.8	3.1	1.5	1.5	1.8	3.5	11.8	2.36
	L	20	1.9	2.4	1.7	1.6	1.1	0.6	1.2	3.3	7.2	
2	R	20	3.09	3.63	2.84	1.27	1.95	1.47	1.55	0.0	0.0	2.48
	L	20	2.25	2.31	3.17	2.74	1.46	1.79	1.81	2.85	6.79	
5	R	20	4.9	6.2	5.3	4.9	3.9	2.4	4.2	8.6	20.5	3.41
	L	20	3.3	3.7	3.8	2.6	3.4	2.1	3.2	6.0	16.6	
9	R	20	6.64	3.97	2.33	2.21	1.06	1.82	1.84	3.49	0.0	3.06
	L	20	2.0	1.89	1.23	3.20	3.71	3.44	2.98	3.50	0.0	
7	R	20	2.85	2.08	1.79	3.59	1.67	0.0	0.0	0.0	0.0	4.75
	L	20	3.41	3.50	4.75	3.32	1.19	1.42	0.0	5.61	0.0	
32	R	20	5.76	0.70	2.65	1.46	0.85	1.23	1.61	0.0	0.0	4.41
	L	20	4.85	4.64	3.70	3.71	3.64	1.35	1.77	0.0	0.0	
39	R	20	10.2	6.37	3.39	1.64	2.02	2.19	1.67	2.55	0.0	1.0
	L	20	27.3	29.7	14.3	1.46	1.50	5.0	3.48	7.55	15.5	

R = Right L = Left

Mean of RMSVA Values for the Non-Contact Transducers

In order to estimate how different the RMSVA values are at 35 and 50 mph, and to determine whether the means of the two samples indicate that both samples were drawn from the same universe, a test to compare the samples was performed. The null hypothesis for the testing was stated as

$$Ho: \mu_{35\ mph} = \mu_{50\ mph}$$

The hypothesis testing was done in order to know whether the RMSVA values are significantly different at 35 and at 50 mph. The variances of the two populations were not assumed to be equal. A value of $\alpha \leq 5$ percent was chosen as a basis for rejecting the null hypothesis. A plot of the values of the significance level versus base length for each device and for every section is shown in Appendix D. Table 4.7 summarizes all the values in which Ho was true (yes) where $\alpha \geq 5$ percent.

A comparison of the means of RMSVA values for the SELCOM and infrared device at both speeds in presented in Table 4.8.

Tables 4.9 and 4.10 contain the mean RMSVA values for the SELCOM and the infrared devices, respectively. These values are for only the right wheel path of each of the profiled sections.

Mean of RMSVA Values for the Standard Profilometer (Wheels)

The means of RMSVA values were calculated for the standard profilometer with 200 and 300-foot-wavelength filters. Tables 4.11 and 4.12 show the values for 200 and 300-foot-wavelength filters. These values are used later in order to make a comparison between the standard profilometer and the non-contact devices.

TABLE 4.7 SUMMARY OF ACCEPTING OR REJECTING THE Ho: $\mu_{35\ mph} = \mu_{50\ mph}$

Section	Device	Speed MPH	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer PSI
6	Selcom	35/50	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	2.36
	Infrared		Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	
2	Selcom	35/50	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	2.48
	Infrared		Yes	Yes	Yes	Yes	Yes	Yes	No	No	Indet	
5	Selcom	35/50	No	No	No	No	No	Yes	Yes	Yes	Yes	3.41
	Infrared		No	No	No	Yes	Yes	No	No	No	Yes	
9	Selcom	35/50	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	3.06
	Infrared		No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	
7	Selcom	35/50	No	No	No	No	No	No	Yes	Indet	Indet	4.75
	Infrared		Yes	No	No	Yes	No	No	Yes	Indet	Yes	
32	Selcom	35/50	No	No	No	No	No	Yes	Yes	Yes	Yes	4.41
	Infrared		Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	

TABLE 4.8 COMPARISON OF MEAN RMSVA AT BOTH SPEEDS

Speed MPH	Mean Infrared > Mean Selcom	Mean Infrared = Mean Selcom	Mean Infrared < Mean Selcom
35	Sections 6 and 7	None	Sections 2, 5, 9 and 32
50	Sections 6 and 7	None	Sections 2, 5, 9 and 32

TABLE 4.9 SELCOM MEAN RMSVA

Section	Wheel Path	Speed MPH	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	35	100.06	29.31	9.20	3.32	1.460	0.76	0.403	0.148	0.043	2.41
	R	50	95.29	28.47	9.24	3.318	1.475	0.771	0.400	0.146	0.041	
2	R	35	142.41	42.06	12.44	4.59	1.831	0.757	0.342	0.180	0.0085	2.47
	R	50	134.9	40.37	12.31	4.56	1.830	0.738	0.331	0.173	0.078	
5	R	35	214.49	55.60	14.55	3.996	1.142	0.372	0.165	0.080	0.023	3.27
	R	50	204.81	51.64	13.65	3.793	1.106	0.363	0.162	0.080	0.021	
9	R	35	157.69	49.14	13.80	4.70	1.605	0.688	0.278	0.121	0.026	3.31
	R	50	130.92	37.12	11.94	4.49	1.567	0.681	0.268	0.121	0.027	
7	R	35	70.24	19.11	4.91	1.377	0.473	0.248	0.153	0.082	0.020	4.8
	R	50	64.61	17.47	4.65	1.306	0.453	0.242	0.151	0.080	0.018	
32	R	35	84.08	22.15	5.79	1.647	0.600	0.352	0.268	0.176	0.068	0.0
	R	50	75.48	20.33	5.41	1.585	0.585	0.350	0.268	0.173	0.0675	

R = Right   L = Left

TABLE 4.10 INFRARED MEAN VALUES OF RMSVA

Section	Wheel Path	Speed MPH	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	35	111.87	41.170	15.181	5.75	2.21	1.003	0.458	0.168	0.050	2.41
		50	112.23	42.019	15.488	5.84	2.22	1.00	0.413	0.153	0.041	
2	R	35	99.27	32.77	10.91	4.52	1.86	0.793	0.338	0.168	0.078	2.47
		50	95.38	32.57	11.49	4.69	1.96	0.831	0.351	0.175	0.080	
5	R	35	106.57	31.97	8.86	2.99	0.983	0.355	0.166	0.081	0.021	3.27
		50	97.23	28.99	8.52	2.96	0.993	0.365	0.156	0.076	0.021	
9	R	35	112.22	37.41	13.08	5.37	1.891	0.810	0.313	0.142	0.030	3.31
		50	106.01	36.14	13.14	5.45	2.00	0.896	0.312	0.138	0.030	
7	R	35	73.93	20.96	5.68	1.59	0.526	0.258	0.153	0.082	0.020	4.8
		50	84.129	23.98	6.58	1.76	0.588	0.278	0.150	0.080	0.020	
32	R	35	53.30	15.99	4.25	1.38	0.577	0.346	0.265	0.175	0.066	4.41
		50	53.15	16.766	4.32	1.38	0.587	0.347	0.261	0.175	0.068	

R = Right L = Left

TABLE 4.11 MEAN RMSVA FOR THE PROFILOMETER WITH 200 WLF

			Base Length (in feet)									
Section	Wheel Path	Speed MPH	0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	20	98.97	34.53	12.52	4.76	1.73	0.84	0.40	0.13	0.03	2.36
	L	20	62.25	22.83	8.28	3.37	1.49	0.78	0.39	0.13	0.03	
2	R	20	134.22	41.04	12.52	4.78	1.85	0.78	0.31	0.11	0.04	2.48
	L	20	155.45	48.18	13.68	4.43	1.56	0.61	0.25	0.10	0.03	
5	R	20	151.78	44.375	12.45	3.70	1.07	0.37	0.16	0.06	0.01	3.41
	L	20	155.76	46.99	13.19	3.87	1.04	0.37	0.15	0.07	0.01	
9	R	20	93.62	30.51	10.60	4.30	1.53	0.70	0.27	0.11	0.02	3.06
	L	20	66.47	20.72	6.32	2.22	0.77	0.33	0.15	0.08	0.02	
7	R	20	43.10	12.41	3.31	1.11	0.41	0.24	0.15	0.07	0.01	4.75
	L	20	39.31	13.41	3.57	1.11	0.42	0.24	0.14	0.07	0.01	
32	R	20	53.94	13.51	3.69	1.28	0.50	0.312	0.224	0.130	0.030	4.41
	L	20	41.84	12.06	3.61	1.42	0.51	0.29	0.20	0.124	0.03	
39	R	20	144.03	48.30	18.45	8.71	4.53	1.40	0.51	0.122	0.030	1.0
	L	20	134.92	45.31	17.33	7.89	3.36	1.22	0.363	0.111	0.032	

R = Right L = Left

TABLE 4.12 MEAN RMSVA FOR THE PROFILOMETER WITH 300 WLF

Section	Wheel Path	Speed MPH	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0	Old Profilometer SIV
6	R	20	101.38	34.81	12.75	4.77	1.72	0.85	0.41	0.14	0.04	2.36
	L	20	61.61	22.25	8.11	3.31	1.48	0.79	0.40	0.15	0.04	
2	R	20	135.27	41.33	12.69	4.78	1.86	0.78	0.34	0.17	0.08	2.48
	L	20	157.10	48.00	13.56	4.41	1.56	0.63	0.28	0.16	0.07	
5	R	20	149.81	44.10	12.33	3.64	1.06	0.38	0.17	0.08	0.01	3.41
	L	20	155.86	45.98	12.98	3.81	1.03	0.34	0.16	0.08	0.02	
9	R	20	95.43	31.21	10.69	4.33	1.54	0.71	0.29	0.13	0.03	3.06
	L	20	66.65	20.59	6.32	2.23	0.78	0.34	0.17	0.10	0.03	
7	R	20	43.13	12.47	3.36	1.11	0.42	0.25	0.16	0.09	0.02	4.75
	L	20	39.05	13.23	3.60	1.11	0.43	0.24	0.15	0.08	0.02	
32	R	20	53.46	13.23	3.70	1.28	0.528	0.362	0.278	0.180	0.07	4.41
	L	20	40.20	11.58	3.53	1.39	0.53	0.33	0.25	0.170	0.07	
39	R	20	145.53	47.84	18.30	8.68	4.52	1.400	0.527	0.138	0.40	1.0
	L	20	136.02	48.14	17.88	7.99	3.40	1.22	0.367	0.131	0.041	

R = Right L = Left

COMPARISON OF THE NON-CONTACT TRANSDUCERS WITH THE PROFILOMETER STANDARD EQUIPMENT (WHEELS)

A comparison is presented here between two non-contact transducers (infrared and SELCOM) and the profilometer with the standard tracking wheels running at 20 mph. This comparison is made for the infrared device at 35 mph and the SELCOM at 50 mph. These speeds correspond to the lowest CV values obtained for each device. The comparison is based on both CV values and means of RMSVA values.

Coefficient of Variation

Three sections were selected, each one representing a level of Serviceability Index (SIV). The comparison is carried out for each section.

Section 2. This section has a SIV = 2.48 with a fine surface texture (Fig 4.23). The CV values are very similar for the non-contact devices and for the profilometer with tracking wheels.

Section 5. This section has a SIV of 3.41 (Fig 4.24) with a coarse surface texture (chip seal). The CV values in this section are very close to those on Section 2, and CV values increase only for the long base lengths (64 and 128 feet); it can also be observed that the surface texture does not affect short base lengths as could be expected.

Section 7. This section has a SIV = 4.75 with a fine surface texture (Fig 4.25). The CV values for the infrared device are higher than those for the other devices for the short base lengths (0.5 to 16 feet). The other devices (SELCOM and the standard profilometer) show low values of CV (around 4 percent); only the 128-foot-base length for the SELCOM shows large values of CV (20 percent).

From the repeatability stand point, as expressed by the coefficient of variation, it can be concluded that the infrared, the SELCOM, and the standard profilometer have approximately the same values. Therefore the repeatability is about the same for all the devices.

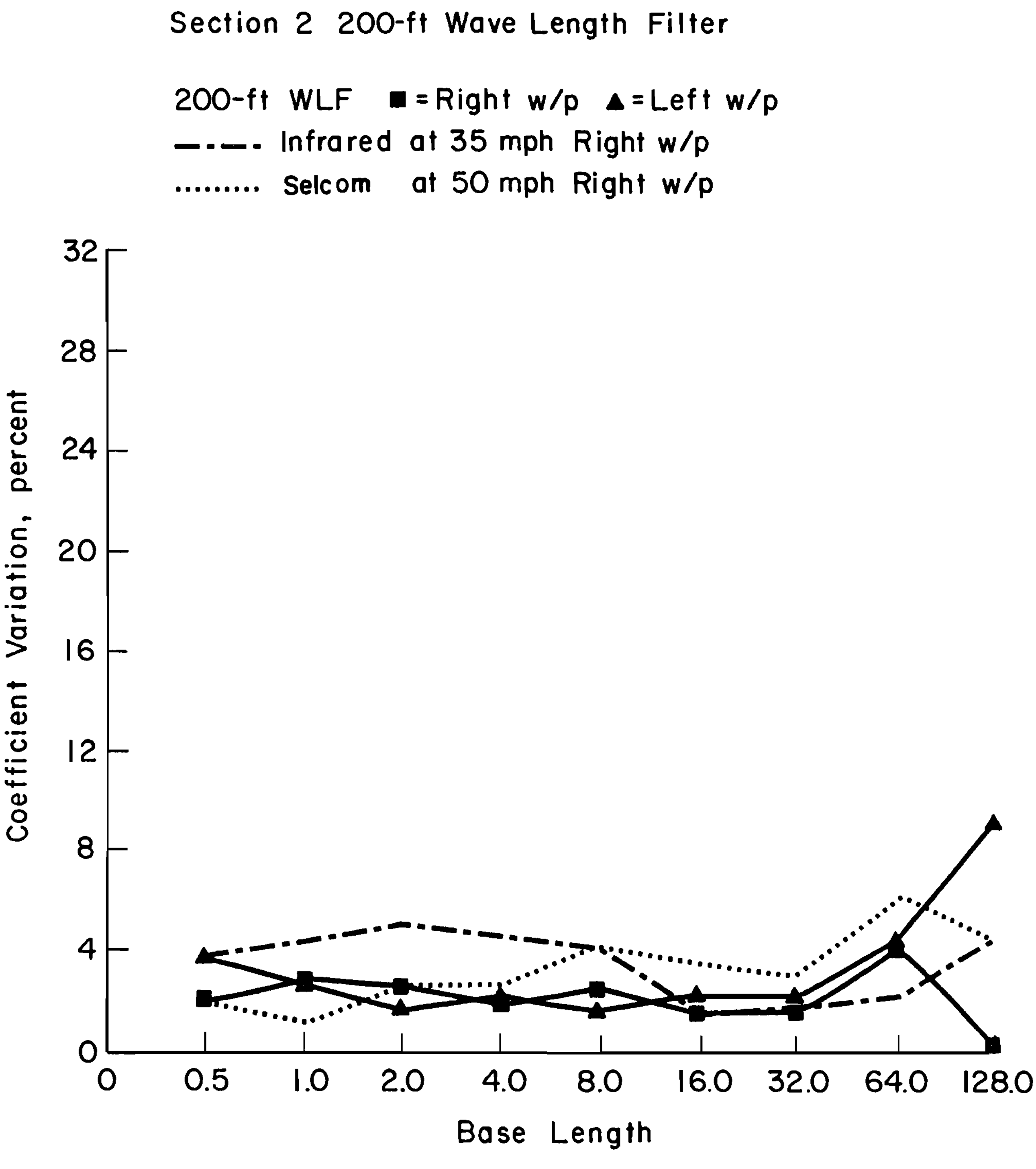


Fig 4.23. Section 2 CV percent versus baselength comparison.

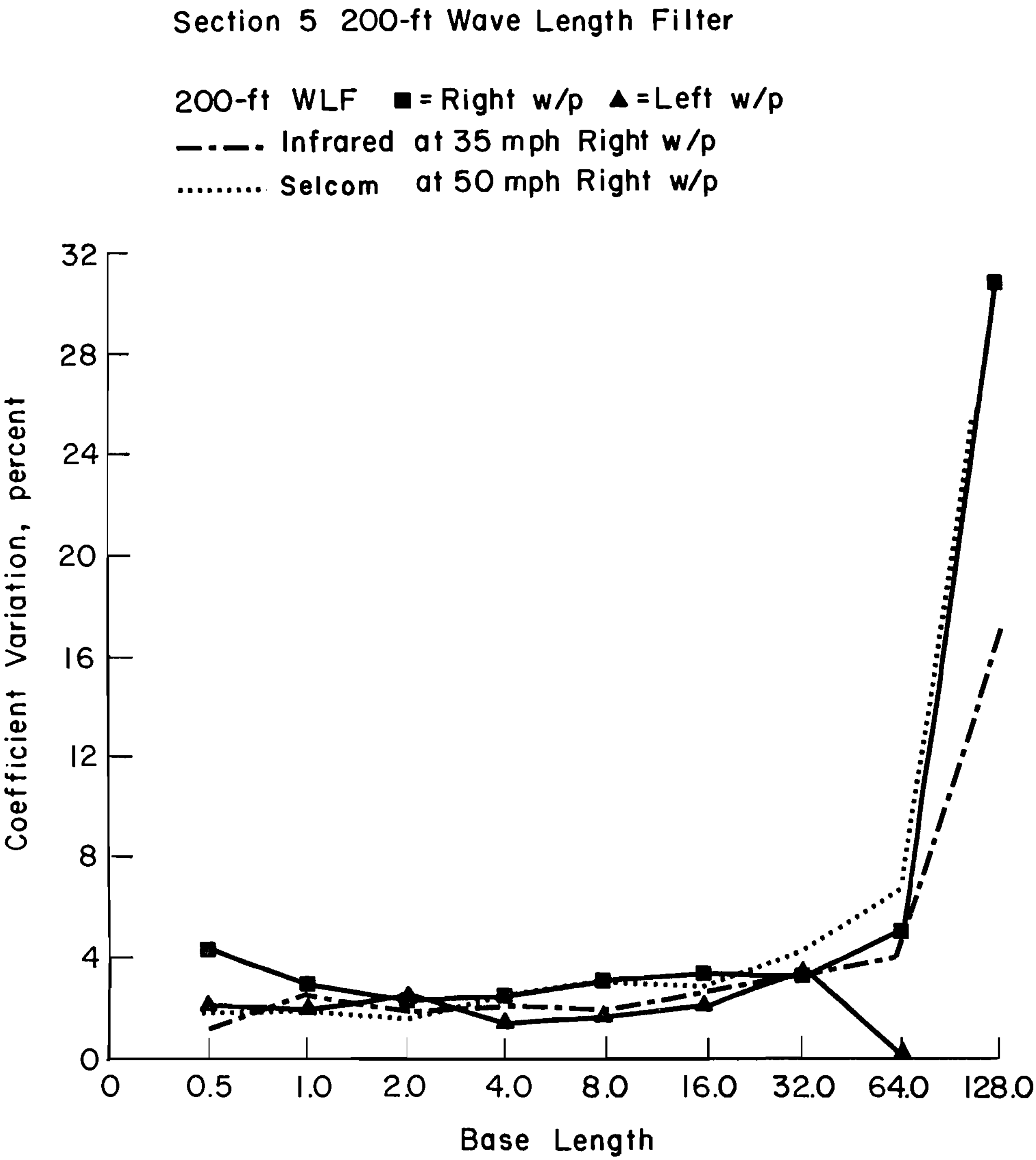


Fig 4.24. Section 5 CV percent versus baselength comparison.

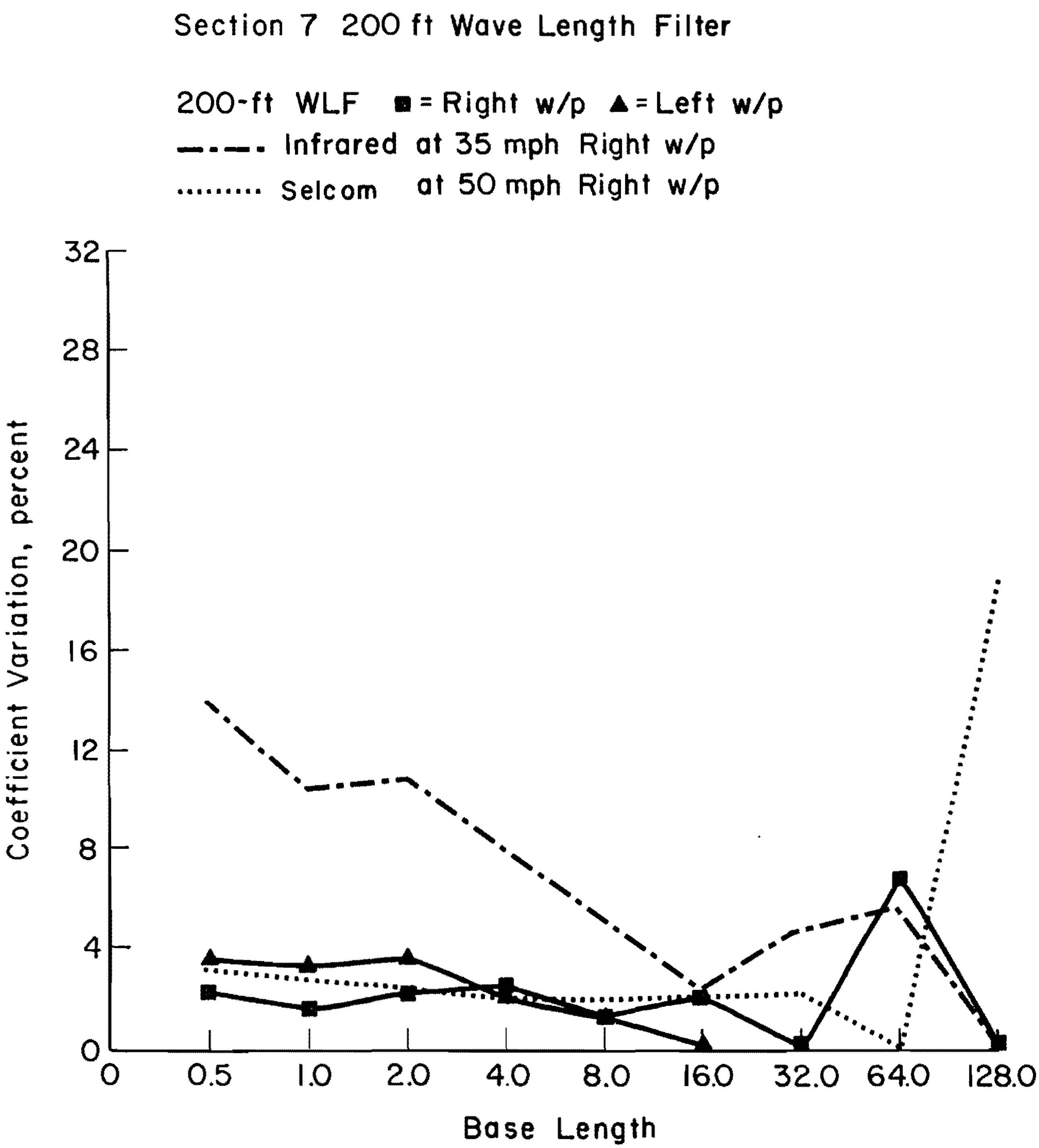


Fig 4.25. Section 7 CV percent versus base length comparison.

Mean of RMSVA Values

In order to perform a preliminary comparison of the means of RMSVA values, the same sections (2, 5, and 7) were used. Figures 4.26, 4.27, and 4.28 show the means of RMSVA values versus base lengths for each one of the devices at the speeds selected above. It can be observed that the mean RMSVAs are different for each of the devices in the short base length (0.5 to 2.0) whereas the values for the long base length agree very well.

Analysis of the Factorial Experiment

An analysis of the full factorial is presented. A series of six sections with three levels of serviceability index (SIV) were profiled with the non-contact devices at two different speeds and with the standard profilometer with two wavelength filters. All these data are included in the analysis of the full factorial (Table 4.1).

Test of Normality. This test is appropriate for testing a composite hypothesis of normality, because it does not use the mean and the variance as part of the hypothesis, as is common in some other tests for normality, such as th Kolmogorov-Smirnov and chi-square tests. This test was developed by Shapiro and Wilk in 1965 (Ref 14) and it is superior in detecting non-normality when evaluated on various symmetric, asymmetric, short, and long-tailed alternatives over sample sizes ranging from 10 to 50.

In order to use this method the following steps must be carried out:

(1) order the n observations as $y_1, y_2, y_3 \cdots y_n$

(2) compute $\Sigma (y_1 - y)^2$

(3) If n is even, n = 2k, compute

$$b = \sum_{i=1}^{k} a_{n-i+1} (y_{n-i+1} - y_i)$$

where the values of a_{n-i+1} appear in Appendix 9 of Ref 14. If n is odd, n = 2k + 1, then omit the sample median, y_{k+1}, and calculate

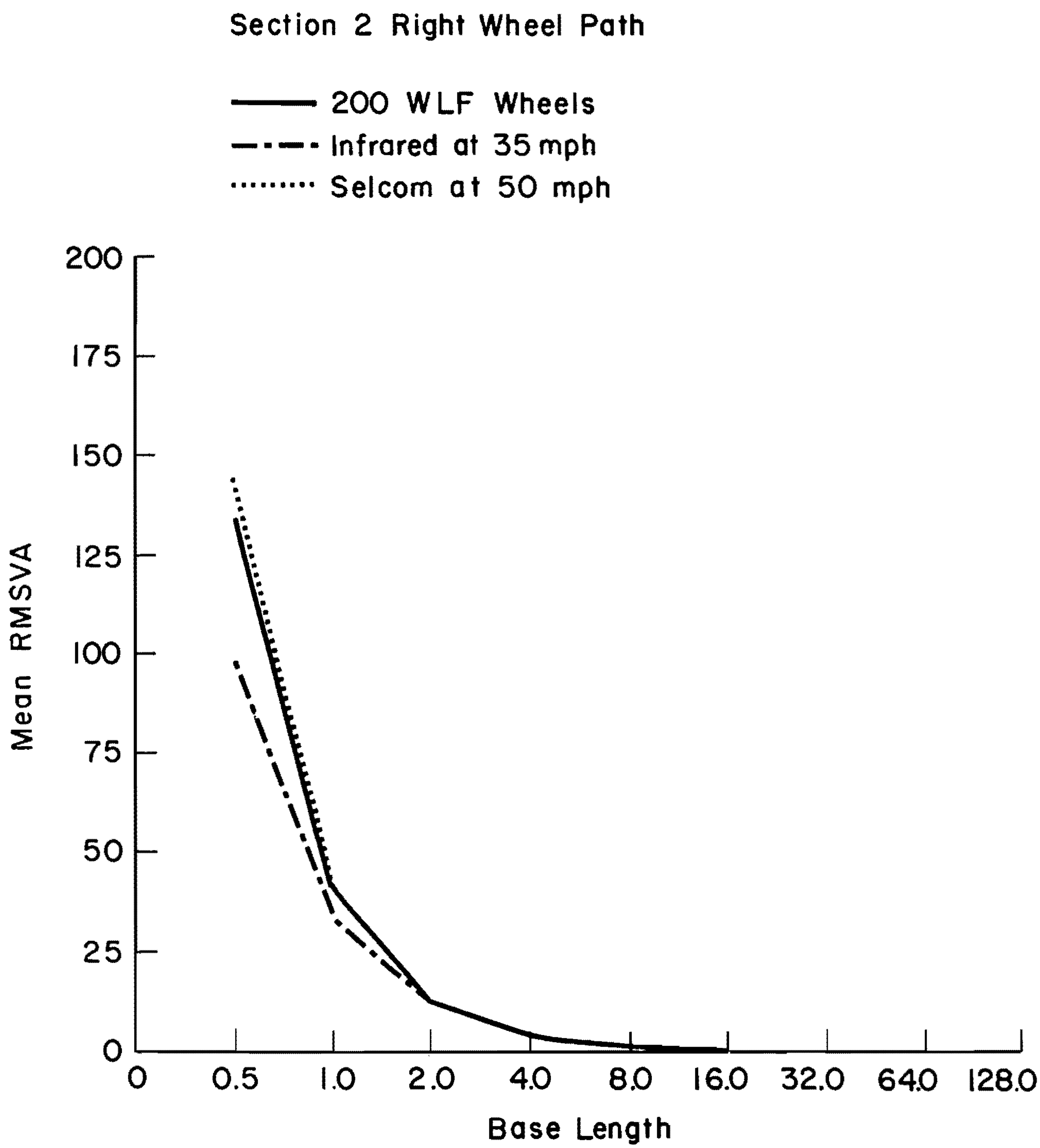


Fig 4.26. Section 2 mean RMSVA versus base length.

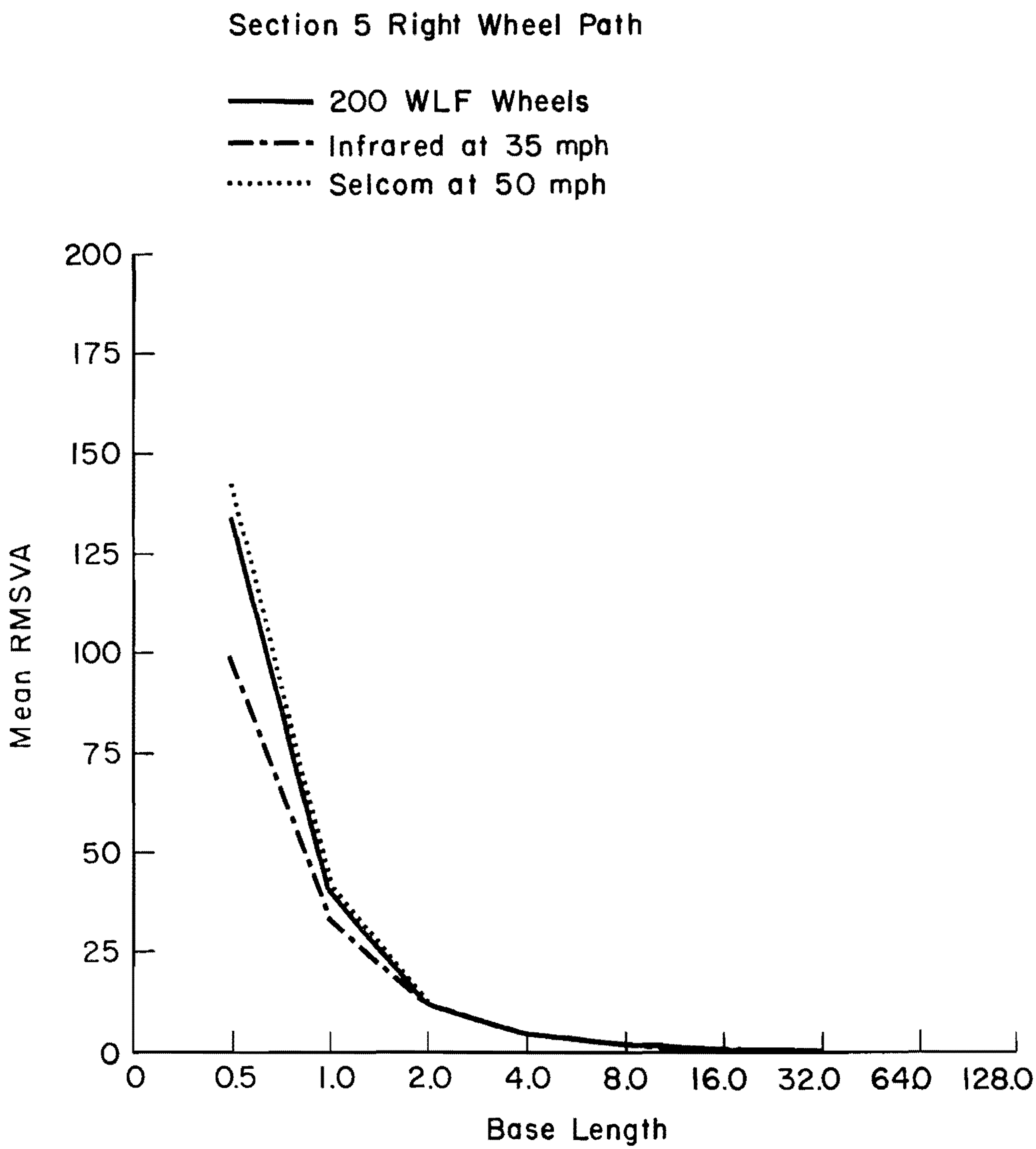


Fig 4.27. Section 5 mean RMSVA versus base length.

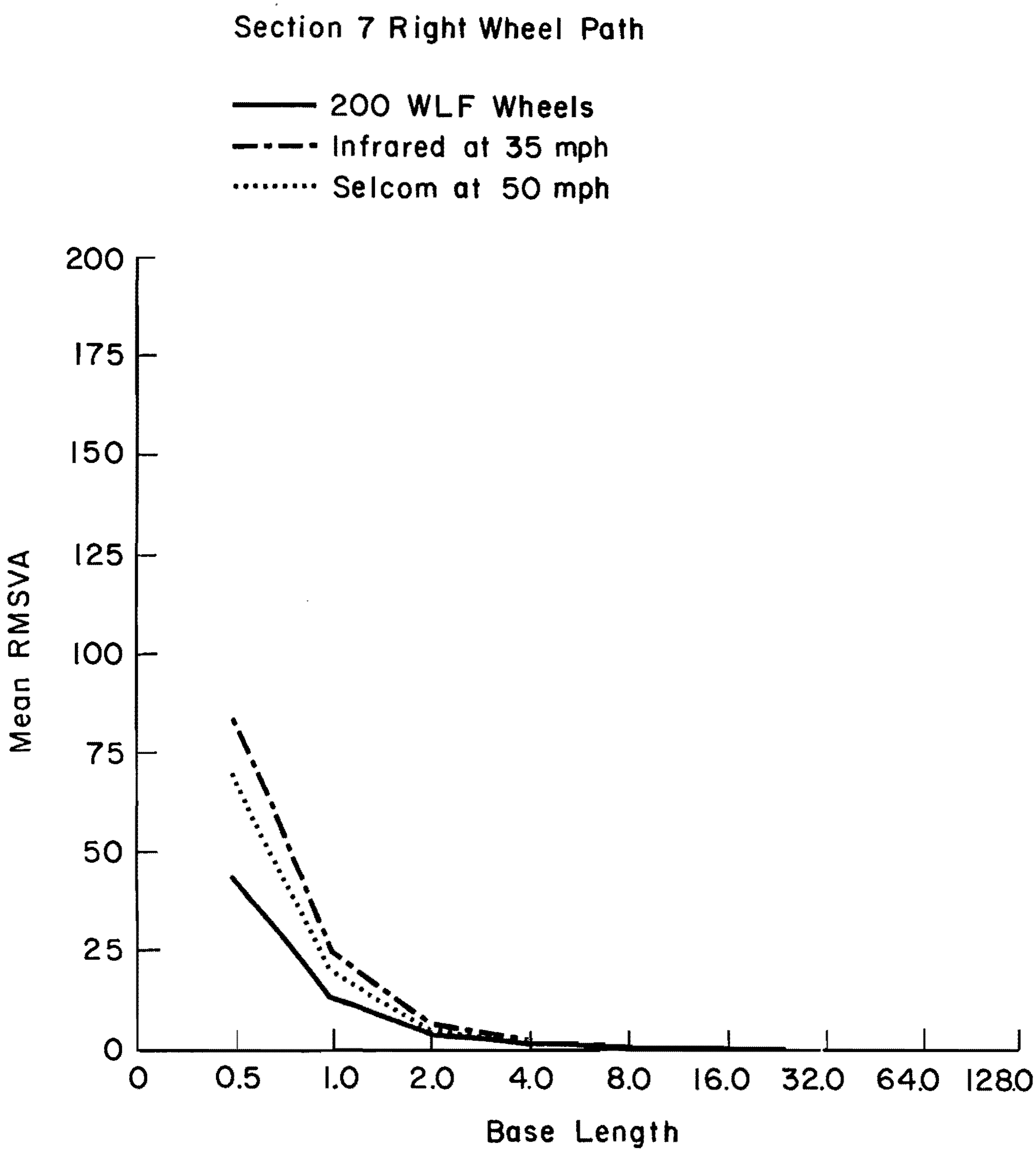


Fig 4.28. Section 7 mean RMSVA versus base length.

$$b = \sum_{i=1}^{k} a_{n-i+1} (y_{n-i+1} - y_i)$$

(4) Compute $W = b^2/\Sigma (y_i - y)^2$

(5) Compare W to the percentage points given in Appendix 10 of Ref 14. A small value of W indicates non-normality. The values of W for the full factorial are shown in Table 4.13 we can conclude the values are normal.

A computer program was written for handling these calculations. This program can process ten columns of data with up to 50 values.

Analysis of Variance

The technique of analysis of variance is a very powerful statistical method. This method provides the basis for determining whether several sample means differ significantly or not.

In an analysis of variance, it is assumed that the sample is random from each population, that each population has a normal distribution, and that all the populations have the same variance (s^2). In practice, the normality assumption is not too important, the equal variances assumption is not important if the sample sizes for the different samples are about the same, but the assumption of random sample is very important.

The analysis of variance in the full factorial was performed using the statistical package Minitab. A two-way analysis was done using the six instruments as one classification and serviceability index (SIV) as a second classification. The F ratios were calculated due to variation of instruments and variation of SI levels:

$$\text{F ratio for instruments} = \frac{\text{Variation due to instruments}}{\text{Variation due to random variation}}$$

$$\text{F ratio for SI levels} = \frac{\text{Variation due to SI levels}}{\text{Variation due to random variation}}$$

TABLE 4.13 NORMALITY TEST (SHAPIRO WILK)

Instrument	Base Length (in feet)								
	0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
Selcom at 35 mph	0.88	0.86	0.83	0.88	0.75*	0.93	0.93	0.84	0.82
Selcom at 50 mph	0.87	0.91	0.84	0.84	0.87	0.75*	0.93	0.82	0.84
Infrared at 35 mph	0.82	0.92	0.93	0.84	0.78	0.77*	0.91	0.75*	0.84
Infrared at 50 mph	0.88	0.96	0.92	0.83	0.74*	0.73*	0.89	0.81	0.84
Tracking Wheel with 200 WLF	0.93	0.86	0.71*	0.78	0.83	0.78	0.91	0.85	0.85
Tracking Wheel with 300 WLF	0.92	0.85	0.72	0.77*	0.84	0.78	0.93	0.91	0.83

* values smaller than 0.788 indicates non normality

In general the null hypothesis was rejected for the two way ANOVA. Table 4.14 shows the different analyses carried out using this test.

Regression Equations

Regression analysis was performed in order to predict the profilometer mean RMSVA with tracking wheels at 20 mph using the mean RMSVA of the non-contact devices. The regression equations have the following general form:

$$Y_i = C_o + C_1 X_i \qquad (4.7)$$

where

Y_i = standard profilometer RMSVA for a base length i,

X_i = non-contact RMSVA for a base length i, and

C_o and C_1 are equation coefficients.

In Tables 4.15 and 4.16 are shown the coefficients C_o and C_1 for 35 and 50 mph. The coefficient of determination (R^2) is also contained in Tables 4.15 and 4.16. It can be observed that the base lengths of 4.0, 8.0, 16.0 and 32.0 feet have the higher coefficient of determination (R^2), indicating that it is possible to predict the RMSVA for the standard profilometer with great confidence using the non-contact probes.

Serviceability Index

The serviceability index obtained with the standard profilometer through a correlation with a rating panel can be predicted with the profilometer with non-contact probes. A multi-linear regression analysis was performed for each device using all the data collected for the six sections.

TABLE 4.14 SUMMARY OF REJECTION IN THE TWO-WAY ANOVA

Type of Analysis	F Ratio Associated with	Base Length (in feet) 0.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0	128.0
Two Way ANOVA For Sections 6, 5, and 7	Instruments	No	No	No	No	No	No	No	No	No
	SIV Levels	No	No	No	No	No	No	No	No	No
Two Way ANOVA For Sections 2, 9, 32	Instruments	No	No	No	No	No	No	No	No	No
	SIV Levels	No	No	No	No	No	No	No	No	No
Two Way ANOVA For All Sections	Instruments	No	No	No	No	No	No	Yes	No	No
	SIV Levels	No	No	No	No	No	No	No	No	No

Note: Yes to not reject Ho, and No rejecting Ho
For instruments Ho $= \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$
For SI levels Ho $= \mu_{SIV\ (Lev\ I)} = \mu_{SIV\ (Lev\ II)} = \mu_{SIV\ (Lev\ III)}$

TABLE 4.15 REGRESSION COEFFICIENT FOR SELCOM DEVICE TO PREDICT STANDARD PROFILOMETER RMSVA

MPH	Base Length l in feet	Intercept C_0	Coefficent C_1	Regression Coefficient (R^2) Adjusted for d.f. in Percent
35	0.5	7.16	0.693	70.8
	1.0	1.73	0.764	62.5
	2.0	-0.156	0.923	66.3
	4.0	-0.142	1.062	77.9
	8.0	-0.129	1.11	94.8
	16.0	-0.055	1.12	99.2
	32.0	-0.0047	0.958	95.9
	64.0	0.0247	0.587	69.2
	128.0	0.0050	0.416	81.1
50	0.5	6.52	0.760	78.8
	1.0	-2.07	0.966	80.5
	2.0	-1.03	1.07	77.8
	4.0	-0.185	1.10	82.0
	8.0	-0.108	1.10	96.1
	16.0	-0.526	1.13	99.2
	32.0	-0.036	0.972	95.2
	64.0	-0.0214	0.623	72.6
	128.0	-0.0047	0.443	81.8

TABLE 4.16 REGRESSION COEFFICIENT FOR INFRARED DEVICE TO PREDICT STANDARD PROFILOMETER RMSVA

MPH	Base Length i in feet	Intercept C_0	Coefficent C_1	Regression Coefficient (R^2) Adjusted for d.f. in Percent
	0.5	-22.5	1.28	39.2
	1.0	- 2.85	1.07	47.7
	2.0	0.773	0.871	60.2
	4.0	0.331	0.831	82.9
35	8.0	0.0878	0.816	90.8
	16.0	0.0467	0.831	96.6
	32.0	0.0189	0.827	98.8
	64.0	0.0115	0.663	92.0
	128.0	0.0022	0.479	91.5
	0.5	- 7.17	1.13	30.8
	1.0	-0.287	0.987	42.1
	2.0	0.849	0.840	53.2
	4.0	0.313	0.818	81.7
50	8.0	0.0716	0.798	91.1
	16.0	0.0451	0.799	96.1
	32.0	0.0105	0.883	96.0
	64.0	0.0194	0.619	82.1
	128.0	0.0041	0.445	82.1

The best regression equation for the infrared device at 50 mph is

$$SI = 5.5913 - 6.0268\ x_1 + 13.678\ x_2 - 7.9256\ x_3$$

$$R^2 = 0.983 \qquad (4.8)$$

where

x_1 = RMSVA for an 8.0-foot base length,

x_2 = RMSVA for a 16.0-foot base length, and

x_3 = RMSVA for a 32.0-foot base length.

The regression equation for the SELCOM device at 50 mph is

$$SI = 6.911 - 7.7725\ x_1 + 4.0807\ x_2 + 81.654\ x_3$$

$$R_2 = 0.998 \qquad (4.9)$$

where

x_1 = RMSVA for an 8.0-foot base length,

x_2 = RMSVA for a 16.0-foot base length, and

x_3 = product of (RMSVA) 4.0 and (RMSVA) 8.0.

DEFICIENCIES OF THE NON-CONTACT TRANSDUCERS

During the study of the different non-contact transducers a series of problems were encountered. A description of these problems for each device is presented herein.

Infrared Transducers

The infrared transducers average the height for all the points inside the 4-inch diameter spot; therefore, the height at the bottom of any wide crack or joint is included in the average height. The relationship of output voltage versus height obtained in the bench calibration gives an s-shape curve. Fitting a linear relationship for voltage versus height gives approximately a ± 0.10-inch error at the extreme range of measurements.

The infrared spot size is fairly large, which reduces the accuracy in the height measurement. Recently, Southwest Research Institute indicated that a reduction in the spot size can be made easily, and that this will result in the additional advantage that the resolution and the linearity of the apparatus will be improved. The spot diameter could be reduced to 2.0 inches.

SELCOM (Laser) Transducer

The most serious disadvantage of this probe is the signal dropout. The light beam is very small (3/8-inch by 1/8-inch). This small size makes it susceptible to sensing the surface texture of the pavement. Coarse surface texture (chip seals) produces a shadowing effect on the scattered light. This causes a dropout in the signal which results in missing data in the profile. During the non-contact probe evaluation, a digital filter was used inside the VERTAC program in order to eliminate all these points from the profile. Fewer dropouts were experienced as the speed of the profilometer was increased up to 50 mph. The SELCOM sales representatives recently indicated that an increase in the light intensity and the angle of the camera viewer could minimize the signal dropout.

K. J. Law Non-Contact Transducer

A change in the type of target surface changes the voltage reading without a change in height. It was observed that a change from a natural wood surface to a white surface changed the reading output by 0.13-inch (-0.075 volts). A change from a white surface to a black surface produced approximately the same change in the output signal. An external light source also produced some change in the output signal without any change in height.

The continuous use of the non-contact device (around three and a half hours) produced a high temperature in the light tower and in the other parts of the non-contact device, which caused some variability in the analog output signal.

This type of sensor (rotating mirrors) involves periodic maintenance. The mirrors should be clean during the profile operations.

A recent communication from K. J. Law indicates that the problem of high temperature in the light tower has been eliminated in a new model by changing the type of bulb in the light tower. It is important to indicate that all the study was done in a prototype model, and according to K. J. Law Engineers all the above problems have now been eliminated.

CONCLUSIONS

Based on this study and the comparison of the non-contact transducers the following conclusions are drawn:

(1) The means of RMSVA values calculated from data measured by the infrared device, the SELCOM transducer, and the standard profilometer (with tracking wheels) have approximately the same coefficient of variation (CV). Therefore the repeatability is about the same for all the devices.

(2) The means of RMSVA values remain constant for the long base lengths (4.0, 8.0, 16.0, 32.0, 64.0, 128.0 feet) for all devices, whereas for the short base lengths (0.5, 1.0 and 2.0 feet) the mean of RMSVA values is different for each of the transducers.

(3) The standard profilometer RMSVA for 4.0, 8.0, 16.0 and 32.0-foot base lengths can be predicted with great accuracy with the non-contact probes, as is shown in Tables 4.15 and 4.16.

(4) The Serviceability Index can be predicted using the regression Eqs 4.8 and 4.9. The inference space for SI is from 0.5 to 4.0.

(5) The profiling wheels can be replaced by the non-contact transducers (SELCOM and infrared), which have the same accuracy, in addition to the following advantages:

(a) The speed of the profilometer can be increased up to 50 mph. This capability is desirable on freeways with high traffic volumes, where it is prohibitively expensive to close down a lane to conduct a profiling operation.

(b) Sections with high levels of roughness tend to damage the potentiometers in the standard profilometer that is equipped with tracking wheels. This problem can be avoided by using the non-contact transducers.

(c) High-frequency vibrations are transmitted by the trailing arm to the frame of the car in the standard profilometer. This high-frequency vibration affects the integration of accelerometer signal producing some error in the double integration of the vertical acceleration. This vibration-related problem can be eliminated by using non-contact transducers.

CHAPTER 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The present research has attempted to gain more information and understanding on dealing with road profile and road roughness. A particular device (the 690D SD profilometer) was studied in order to evaluate its capabilities and limitations. The two main objectives of this study were: (1) to develop a correlation between the analog (old) profilometer and the digital 690D (new) profilometer, and (2) to evaluate three different non-contact transducers on the profilometer in order to make it possible to increase the profilometer speed during the profiling process. The essential points discussed in this report, its conclusions and recommendations are set forth in the following sections.

SUMMARY AND CONCLUSIONS

In Chapter 2, conventional methods for processing road profile data are described. The RMSVA method was selected for this study because it has been successfully used by the Texas State Department of Highways and Public Transportation (SDHPT) in recent years as a basis for predicting serviceability index and for calibrating Maysmeters. The great advantage of this method is that it provides a means for producing RMSVA statistics from a road profile that can be associated with various wavelengths.

An evaluation of non-contact transducers on the profilometer is also reported herein. Based on this study it can be concluded that:

(1) The mean of RMSVA values calculated from data measured by the infrared transducer, the SELCOM (laser) transducer, and the standard profilometer (with profiling wheels) have approximately the same coefficient of variation (CV) in the calculated RMSVA when they are used. Therefore the repeatability is about the same for all the devices.

(2) The standard profilometer RMSVA for 4.0, 8.0, 16.0, and 32.0-foot base lengths can be predicted with great accuracy with the non-contact transducers, as is shown in Tables 4.15 and 4.16.

(3) The profiling wheels can be replaced by non-contact transducers (Selcom and infrared), which have the same accuracy, in addition to the following advantages;

(a) The speed of the profilometer can be increased up to 50 mph. This capability is desirable on freeways with high traffic volumes where it is prohibitively expensive to close down a lane to conduct a profiling operation.

(b) Sections with high levels of roughness tend to damage the potentiometers in the standard profilometer layout. In addition, the bouncing of the wheel deforms the measured profile. These problems can be avoided by using a non-contact transducers.

(c) High frequency vibrations are transmitted by the trailing arm to the frame of the car in the standard profilometer. This high frequency vibration produces some error in the double integration of the vertical acceleration. The solution of this problem is not to use tracking wheels.

(4) In the last part of this study (Chapter 4), two equations were developed in order to predict the serviceability index (SIV) from the old profilometer. These two equations were obtained directly based on RMSVAs. The regression equations are (see Eqs 3.14 and 3.15):

(a) Flexible pavements:

$$SIV_F = 5.029 - 0.424\ VAN_4 - 2.702\ VAN_{64}$$

where

SIV_F = predicted serviceability index for flexible pavements, and

VAN_4 and VAN_{64} = RMSVA for 4 and 64-foot base lengths, respectively.

(b) Rigid pavements:

$$SIV_R = 5.244 - 1.027\ VAN_8 - 10.332\ VAN_{64}$$

where

SIV_R = predicted serviceability index for rigid pavements, and

VAN_8 and VAN_{64} = RMSVA for 8 and 64-foot base lengths, respectively.

It is important to note that the above equations are a provisional method for obtaining the serviceability index using the new profilometer. A definitive method for SI determination is being developed under Research Project 354, "Updated Pavement Ride Quality Evaluation," which is being conducted at the Center for Transportation Research, The University of Texas at Austin. This research will give an updated serviceability index correlated with a new user's panel and shorter wheel base vehicles.

(5) Tables 3.6 and 3.7 shows the correlation coefficients for predicting RMSVA from the old profilometer using RMSVA from the new profilometer for flexible and rigid pavements, respectively. These correlations were developed for the different base lengths.

(6) The Maysmeter simulation value (Mo) was also modified to account for the RMSVAs from the new profilometer. The modified equations for flexible and rigid pavements are

(a) Flexible pavements (see Eq 3.17):

$$CMo_F = -24.5078 + 21.597\ VAN_4 + 56.899\ VAN_{16}$$

where

CMo_F = corrected Maysmeter predicted value for flexible pavement, inch/mile; and

VAN_4 and VAN_{16} = RMSVA from the new profilometer for 4 and 16-foot base lengths, respectively, ft^2/sec^2.

(b) Rigid pavements (see Eq 3.18):

$$CMo_R = 3.7184 + 12.696\ VAN_4 + 57.768\ VAN_{16}$$

where

CMo_R = corrected Maysmeter predicted value for rigid pavements, and

VAN_4 and VAN_{16} = RMSVA from the new profilometer for 4 and 16-foot base lengths, respectively, ft^2/sec^2.

RECOMMENDATIONS

(1) Implementation of non-contact transducers onto the profilometer is recommended, based on the advantages of these devices in the profile operations. Supplementary research will be necessary in order to choose the most effective device.

(2) An update of the serviceability index is badly needed, and Research Project 354 is designed to accomplish this objective. An update of the ride quality is important because it will give a more realistic statement of the pavement condition.

REFERENCES

1. Spangler, E. B., and W.J. Kelley, "GMR Road Profilometer - A Method for Measuring Road Profile," Highway Research Record 121, Highway Research Board, Washington.

2. Walker, R. S., and W. R. Hudson, "The Use of Spectral Estimates for Pavement Characterization," Research Report 156-2, Center for Highway Research, The University of Texas at Austin, August 1975.

3. Hutchinson, B. G., "Digital Computation of Pavment Roughness Power Spectra," Transportation Research Board Mid Year, August 1967.

4. McKenzie, D. W., W. R. Hudson, and C. E. Lee, "The Use of Road Profile Statistics for Maysmeter Calibrations," Research Report 251-1, Center for Transportation Research, The University of Texas at Austin, August 1982.

5. Williamson, H. J., et al, "A Study of the Relationships Between Various Classes of Road Surface Rroughness and Human Rating of Riding Quality," Research Report 156-5F, Center for Highway Research, The University of Texas at Austin, August 1975.

6. Gillespie, T. D., M. W. Sayers, and L. Segel, "Calibration and Correlation of Response-Type Road Roughness Measuring System," NCHRP Project 1-18, 1980.

7. Visser, A. T., and C. A. V. Queiroz, "Roughness Measurement System," Working Document No. 10 of the Research on the Relationship Between Cost of Highway Construction, Maintenance, and Utilization, GEIPOT, Brazilia, July 1979.

8. Nathman, E. D., "Evaluation of Automobile Ride Accelerations with Random Roadway Roughness," Master's Thesis, The University of Texas at Austin, August 1973.

9. "Selcom Operator's Manual," Selective Electronics Co., (unpublished).

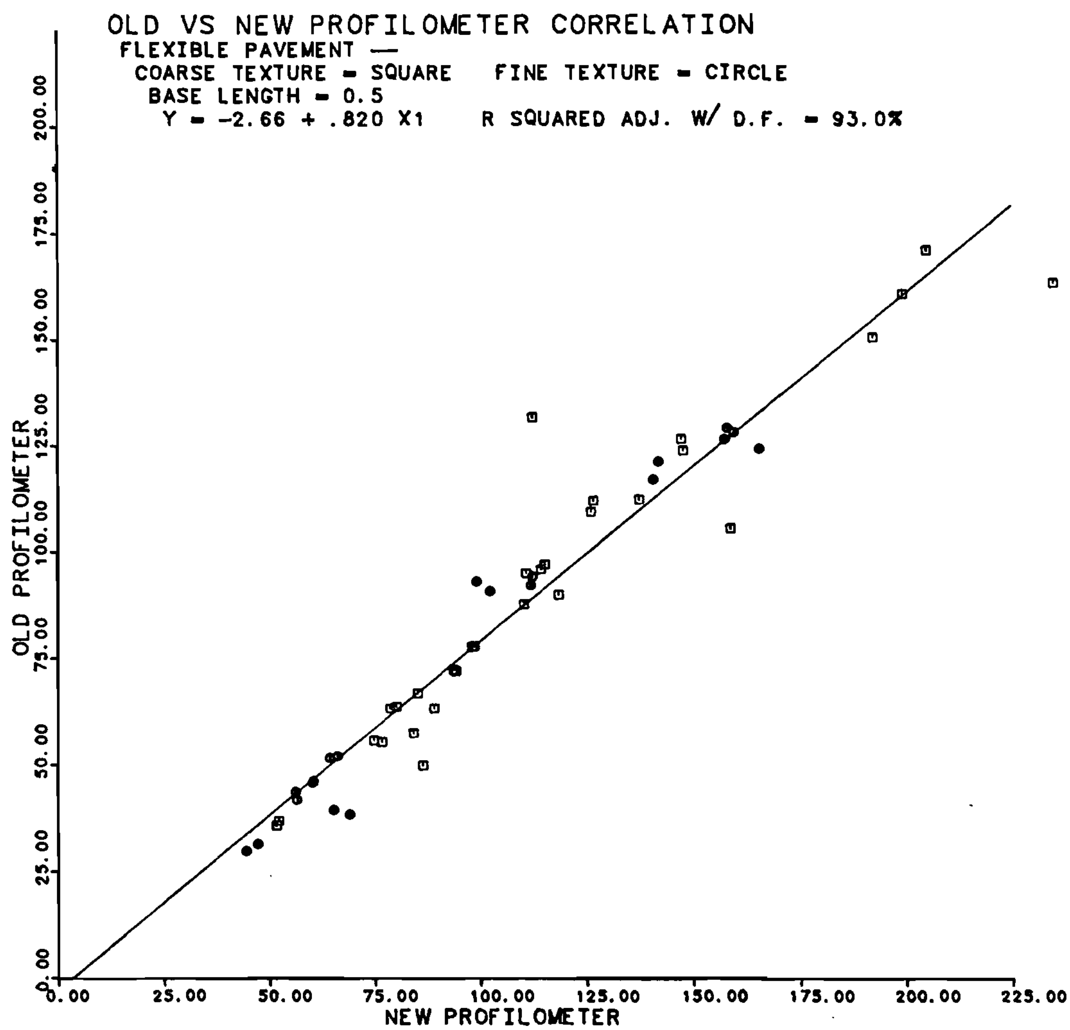
10. Still, P. B., and M. A. Winnett, "Development of a Contactless Displacement Transducer," Laboratory Report 690, Transportation and Road Research Laboratories, Crawthrone, Perkshire, England, 1975.

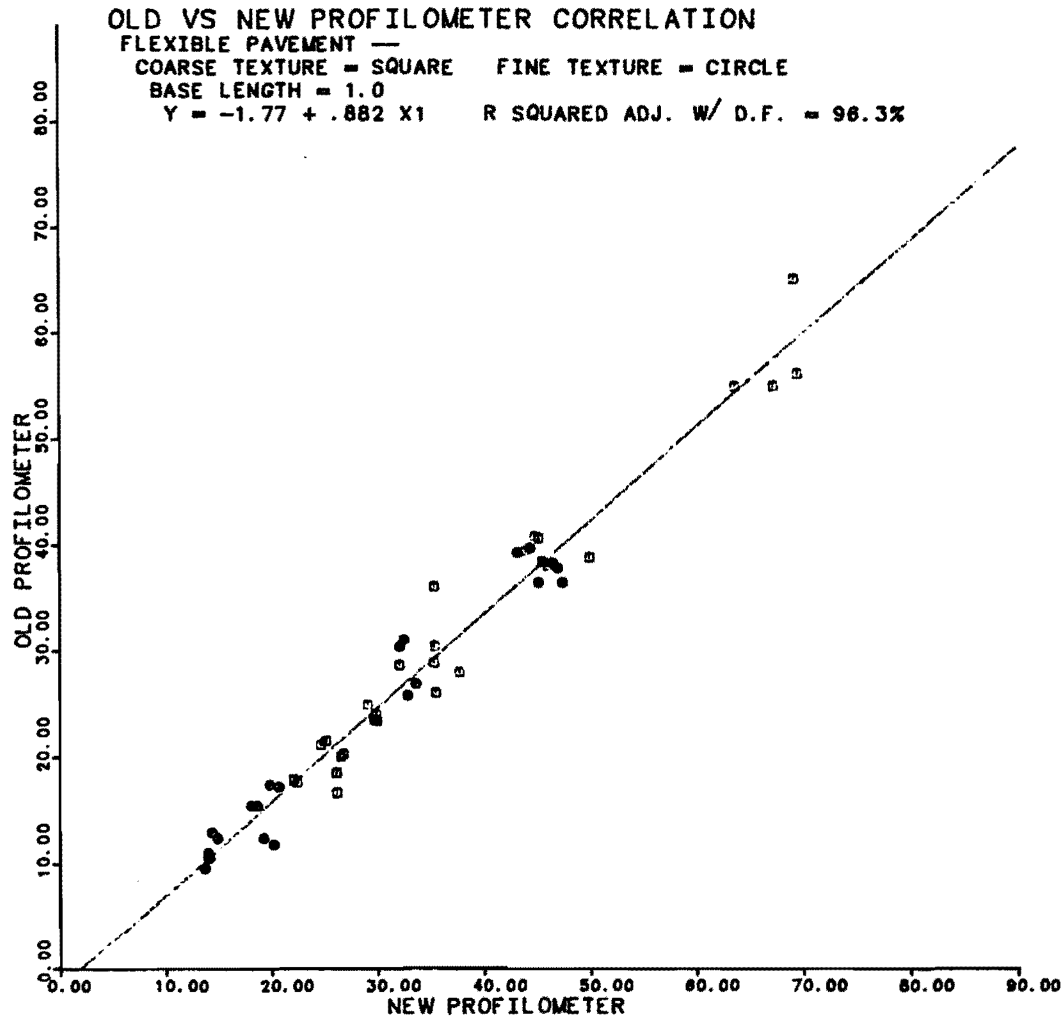
11. "System for Inventorying Road Surface Topography (SIRST)," Report No. FHWA/RD-82/062, Federal Highway Administration, August 1982.

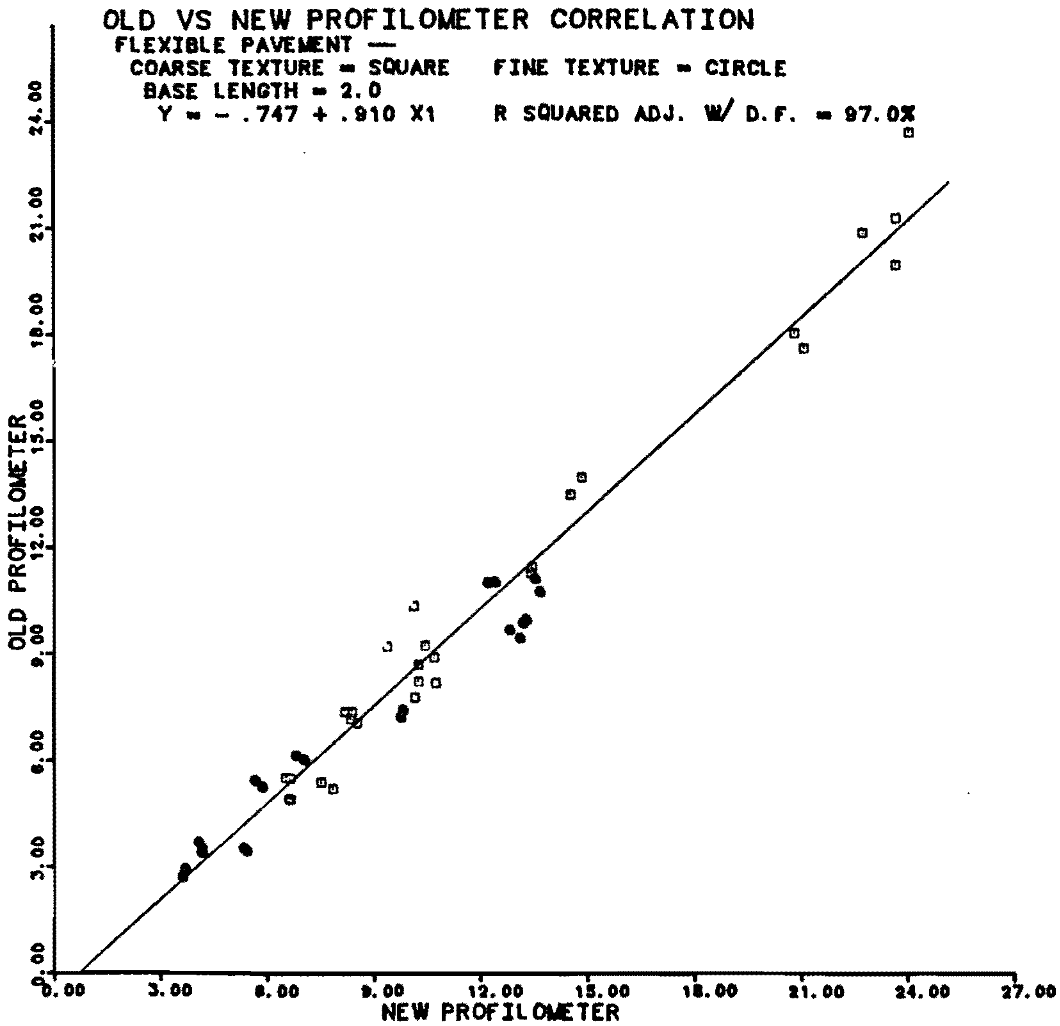
12. Hudson, W. Ronald, "High Speed Road Profile Equipment Evaluation," Research Report 73-1, Center for Hignway Research, The University of Texas at Austin, January 1966.
13. Anderson, V. L., and R. A. McLean, Design of Experiments, Marcel Deckker, Inc., New York, 1972.

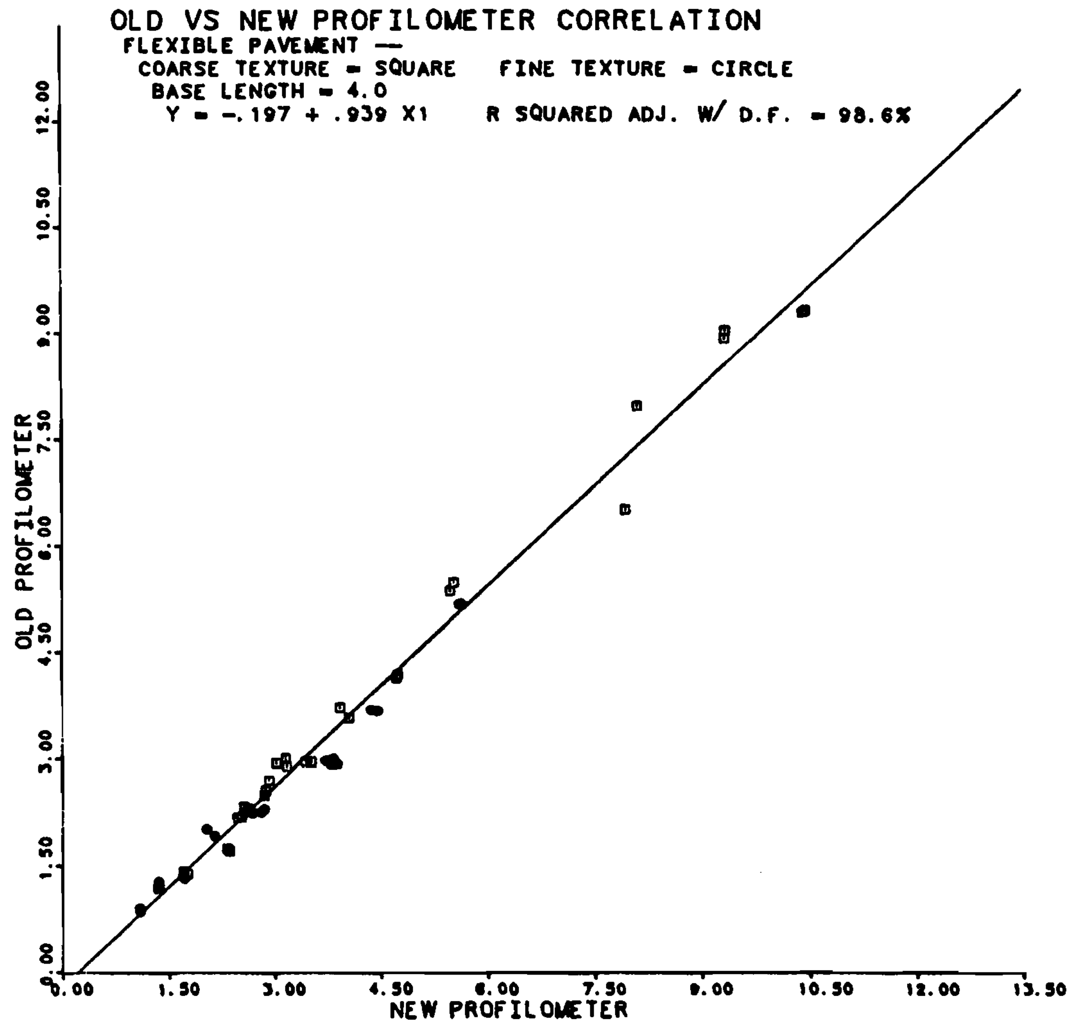
APPENDIX A

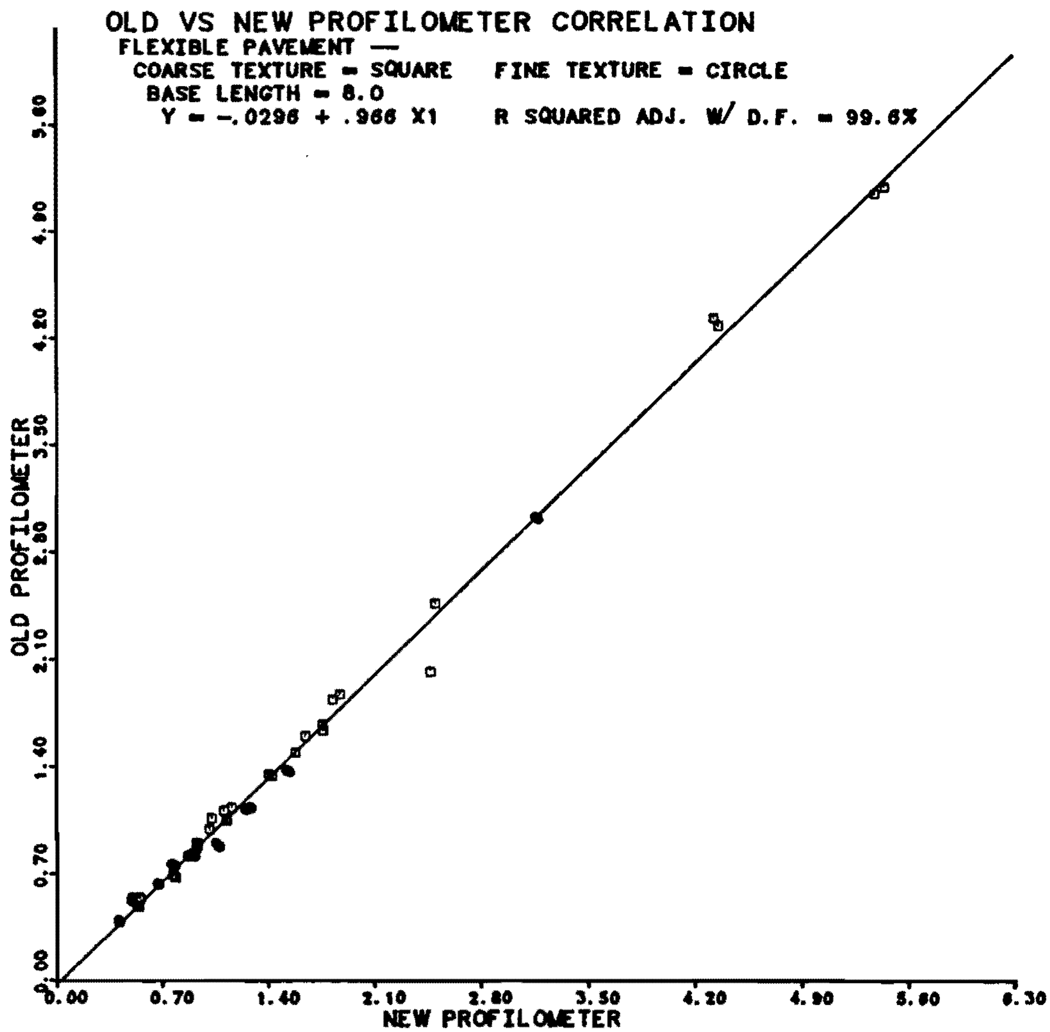
RMSVA PLOTS FOR OLD VERSUS NEW PROFILOMETER FOR RIGID AND FLEXIBLE PAVEMENTS

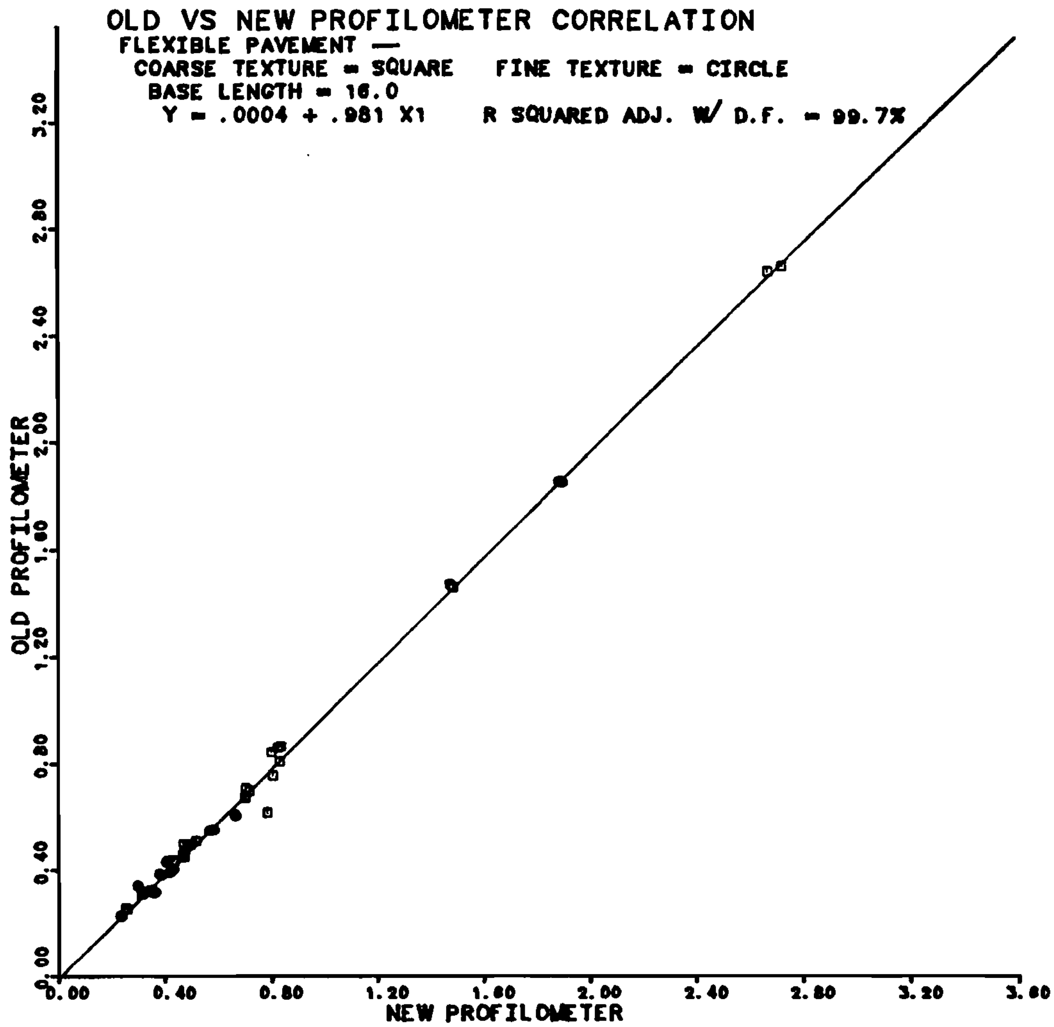

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE FINE TEXTURE = CIRCLE
BASE LENGTH = 0.5
Y = -2.66 + .820 X1 R SQUARED ADJ. W/ D.F. = 93.0%
OLD PROFILOMETER
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225.00
NEW PROFILOMETER

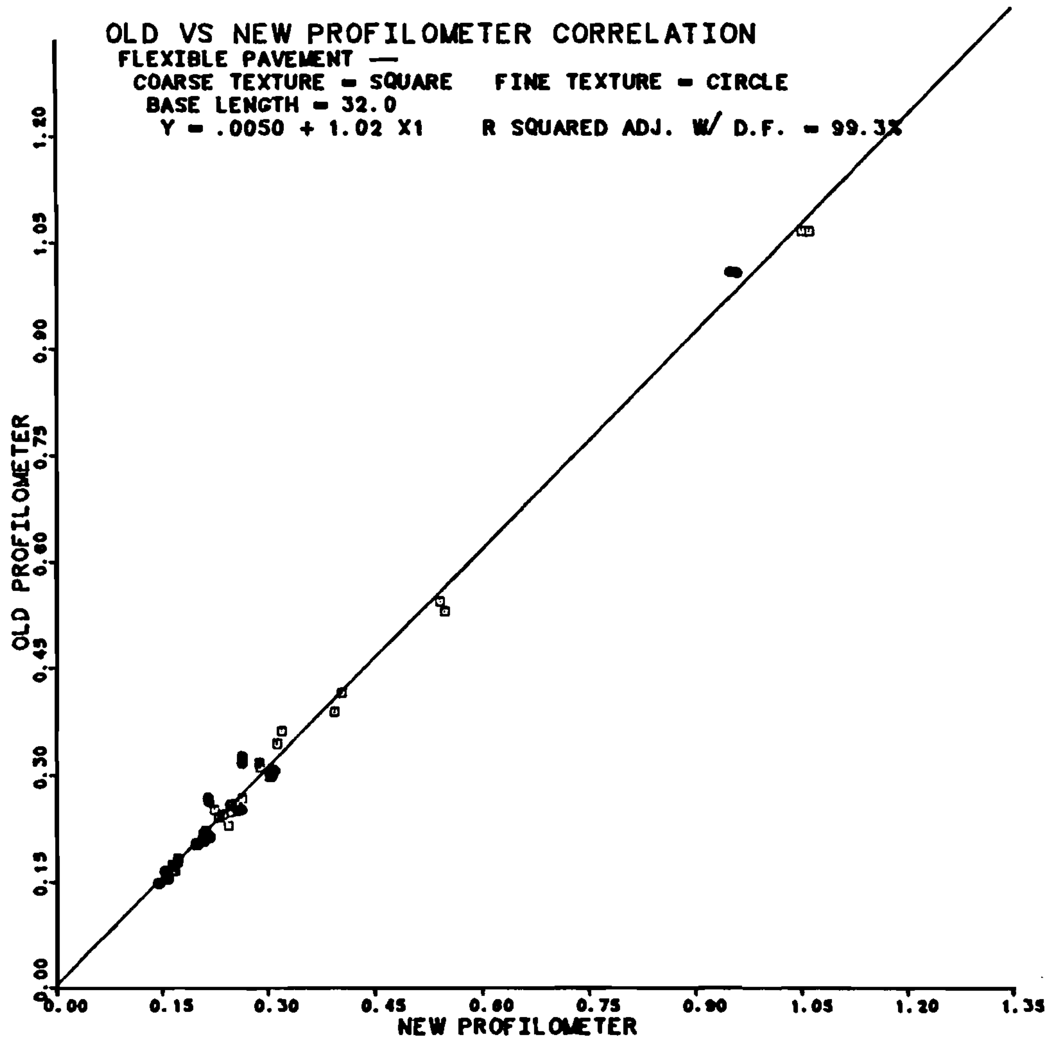

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE FINE TEXTURE = CIRCLE
BASE LENGTH = 1.0
Y = -1.77 + .882 X1 R SQUARED ADJ. W/ D.F. = 96.3%
OLD PROFILOMETER
NEW PROFILOMETER
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00

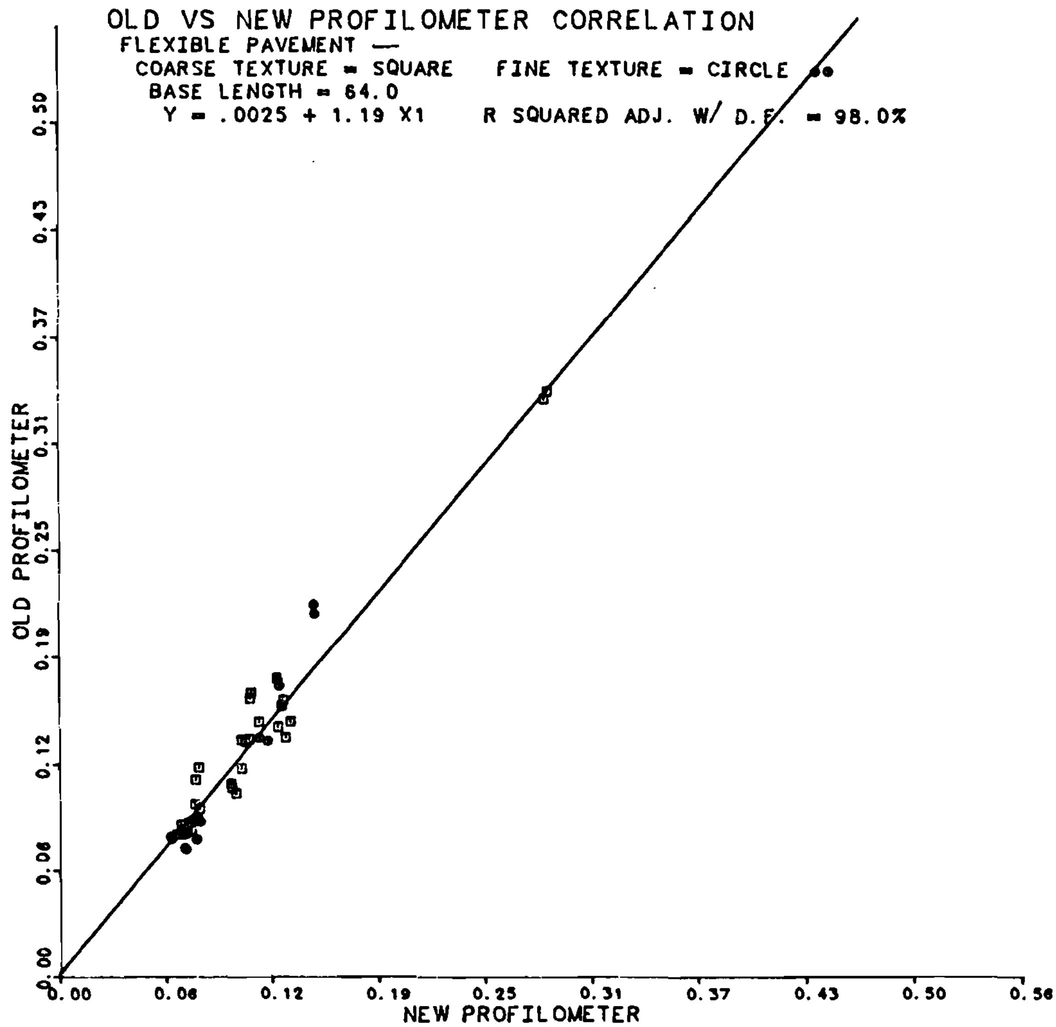

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE   FINE TEXTURE = CIRCLE
BASE LENGTH = 2.0
Y = - .747 + .910 X1   R SQUARED ADJ. W/ D.F. = 97.0%
OLD PROFILOMETER
NEW PROFILOMETER
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00

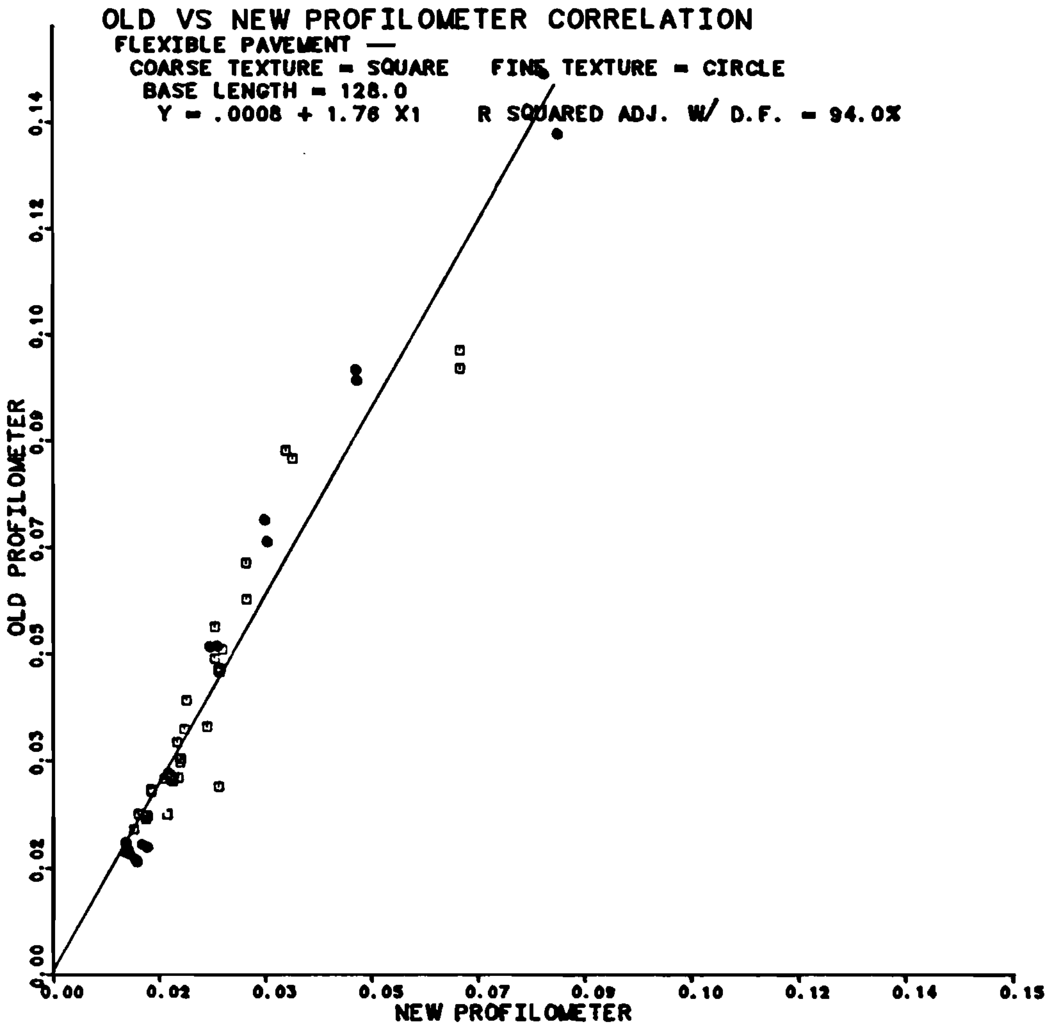

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE   FINE TEXTURE = CIRCLE
BASE LENGTH = 4.0
Y = -.197 + .939 X1   R SQUARED ADJ. W/ D.F. = 98.6%
OLD PROFILOMETER
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
12.00
NEW PROFILOMETER
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
12.00
13.50

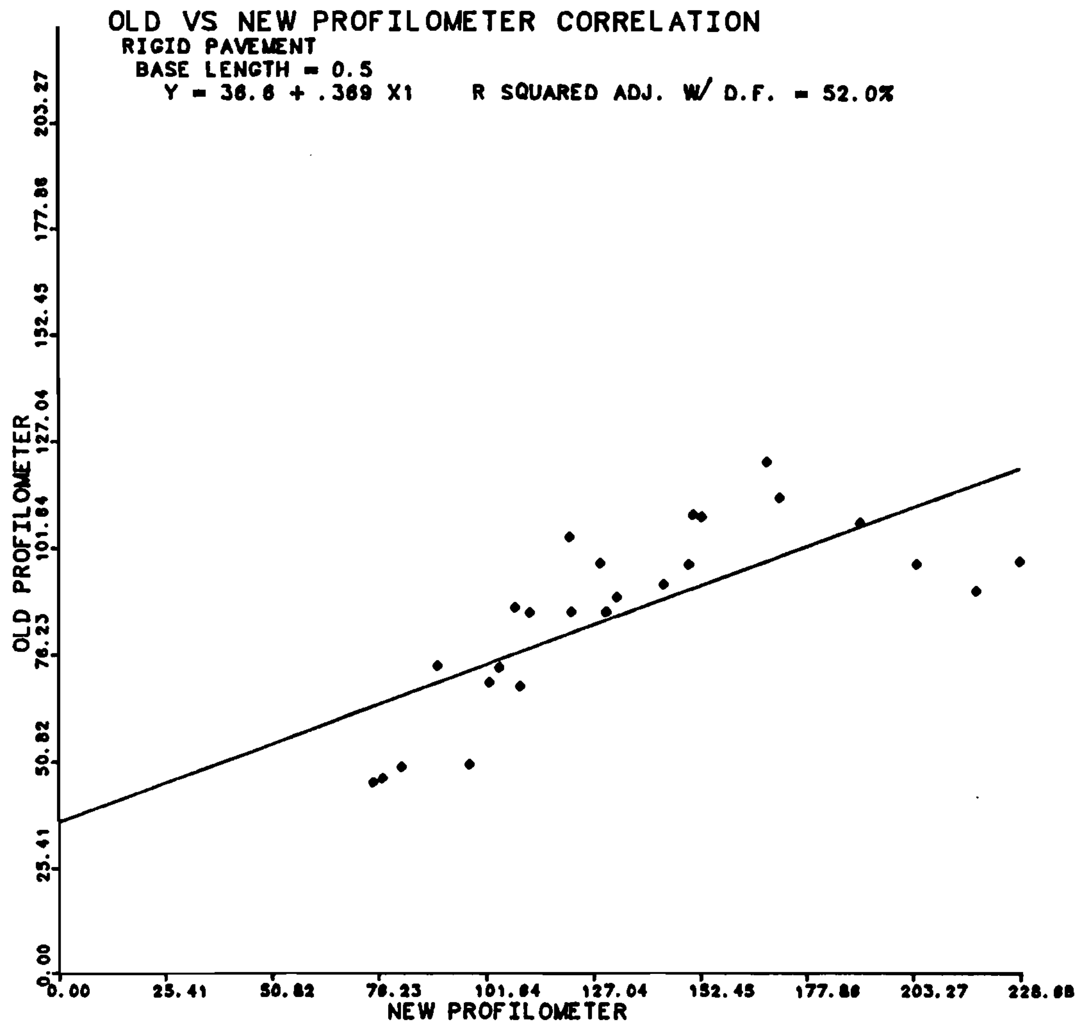

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE   FINE TEXTURE = CIRCLE
BASE LENGTH = 8.0
Y = -.0296 + .966 X1   R SQUARED ADJ. W/ D.F. = 99.6%
OLD PROFILOMETER
NEW PROFILOMETER
0.00
0.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30

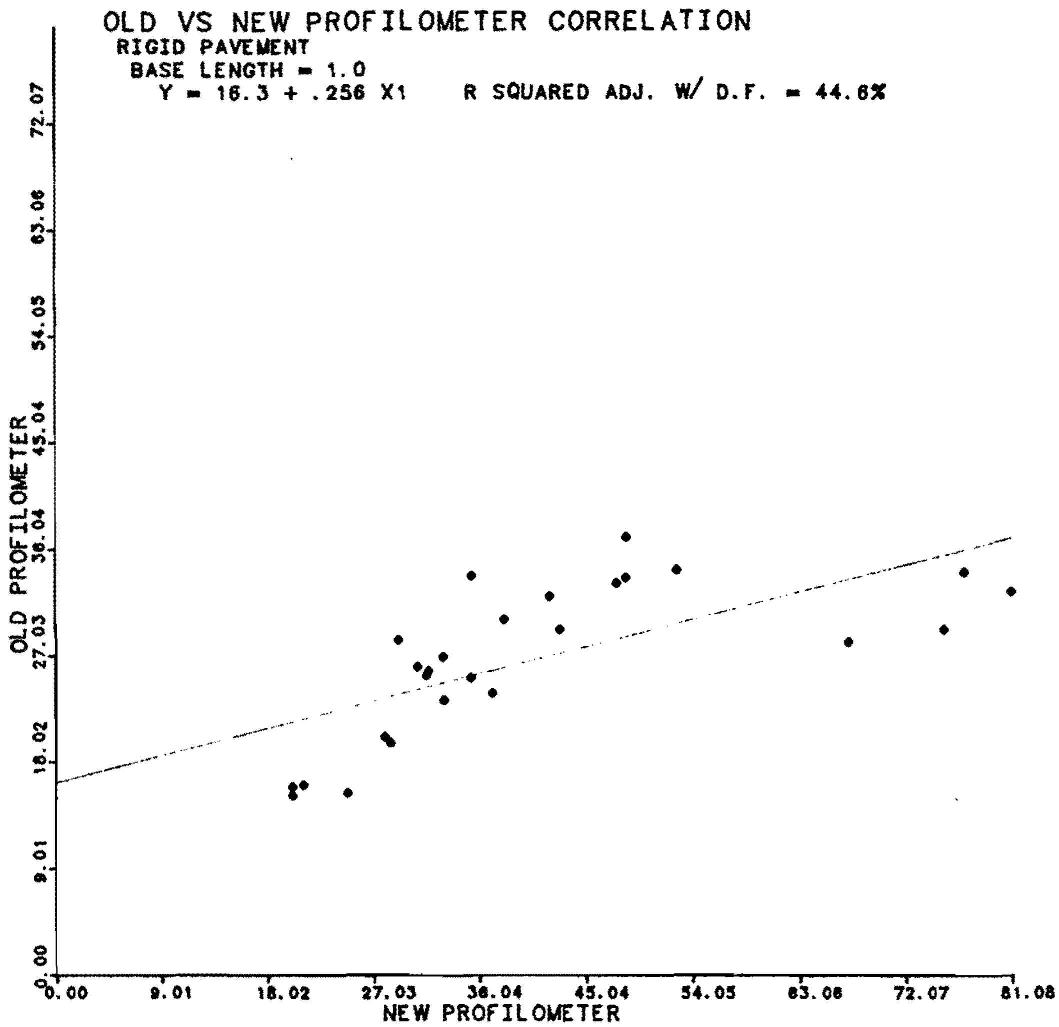

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE   FINE TEXTURE = CIRCLE
BASE LENGTH = 16.0
Y = .0004 + .981 X1   R SQUARED ADJ. W/ D.F. = 99.7%
OLD PROFILOMETER
NEW PROFILOMETER
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60

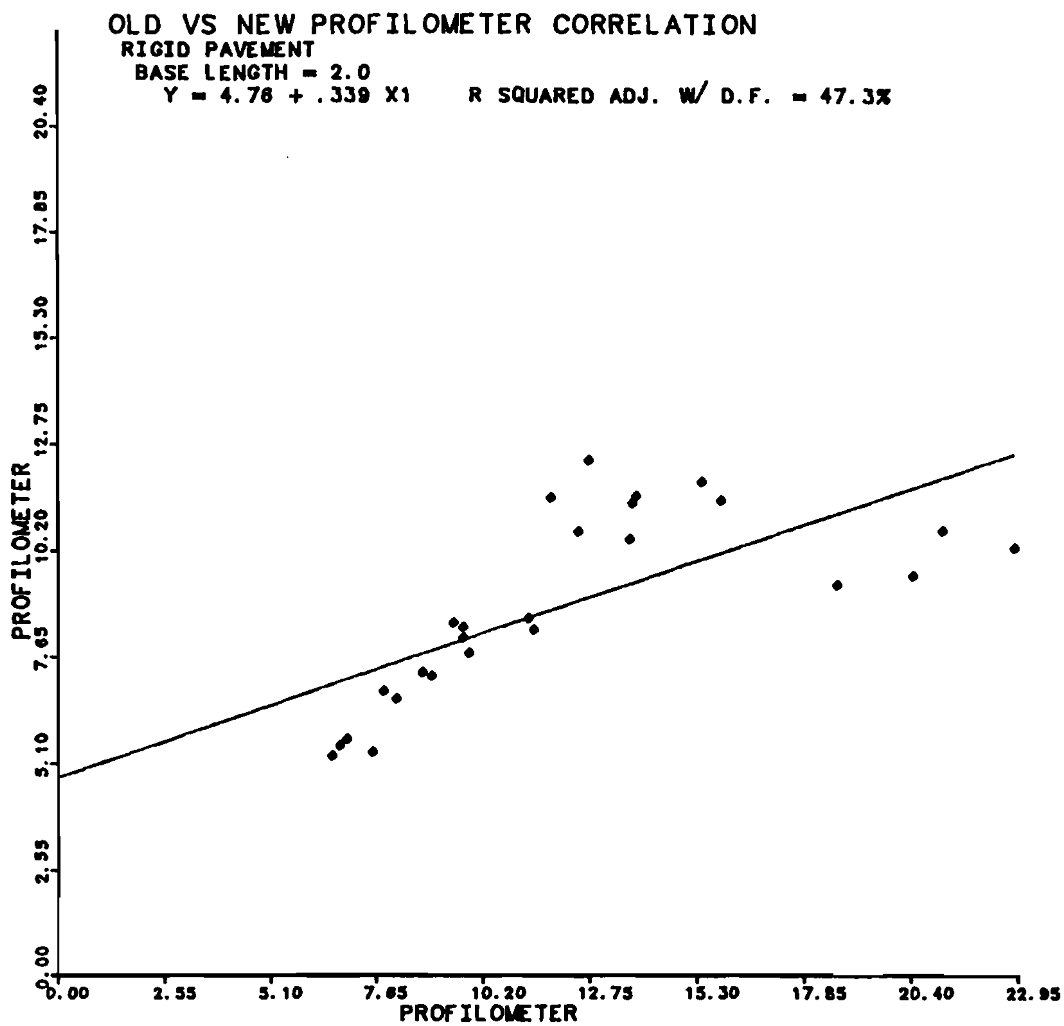

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE FINE TEXTURE = CIRCLE
BASE LENGTH = 32.0
Y = .0050 + 1.02 X1 R SQUARED ADJ. W/ D.F. = 99.3%
OLD PROFILOMETER
NEW PROFILOMETER
0.00
0.15
0.30
0.45
0.60
0.75
0.90
1.05
1.20
1.35

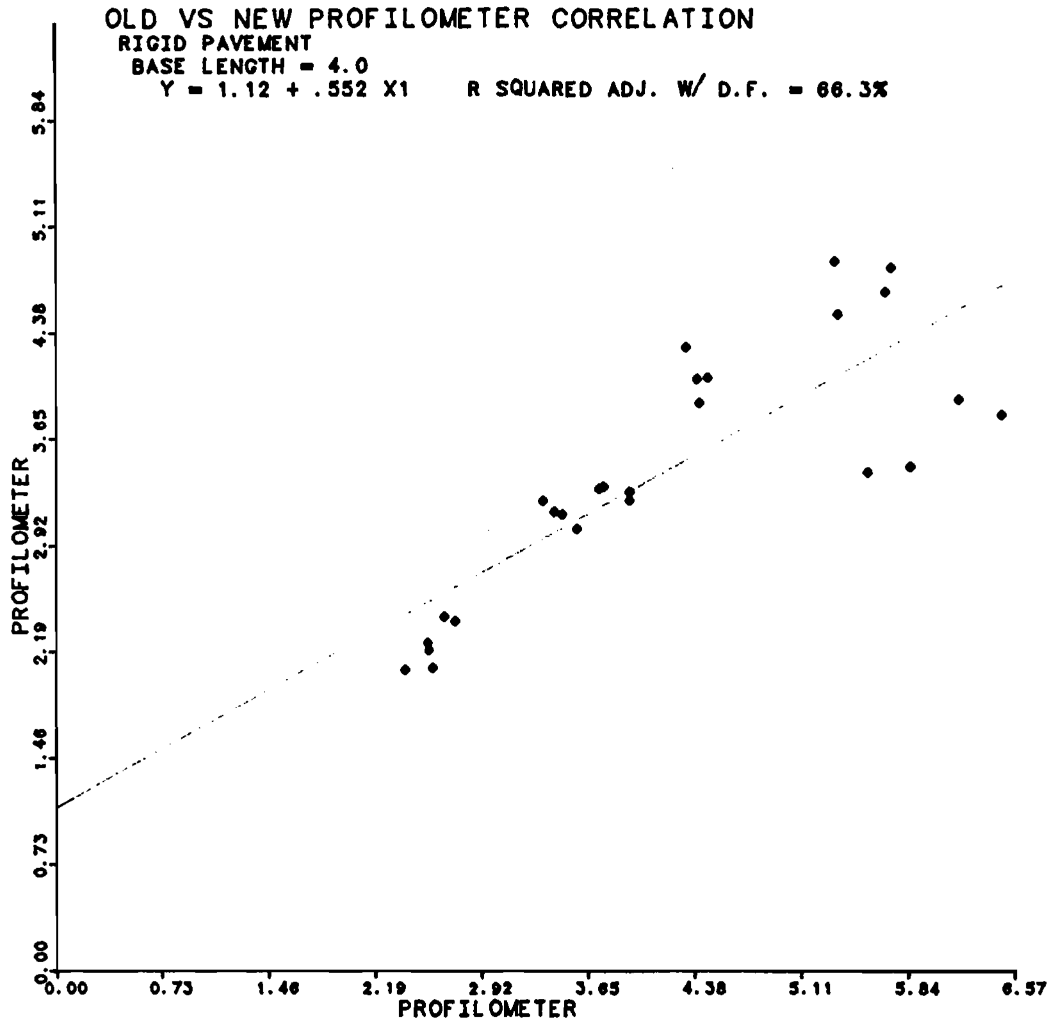

OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE FINE TEXTURE = CIRCLE
BASE LENGTH = 64.0
Y = .0025 + 1.19 X1 R SQUARED ADJ. W/ D.F. = 98.0%
OLD PROFILOMETER
0.00
0.06
0.12
0.19
0.25
0.31
0.37
0.43
0.50
NEW PROFILOMETER
0.00
0.06
0.12
0.19
0.25
0.31
0.37
0.43
0.50
0.56


OLD VS NEW PROFILOMETER CORRELATION
FLEXIBLE PAVEMENT —
COARSE TEXTURE = SQUARE FINE TEXTURE = CIRCLE
BASE LENGTH = 128.0
Y = .0008 + 1.76 X1 R SQUARED ADJ. W/ D.F. = 94.0%
OLD PROFILOMETER
NEW PROFILOMETER
0.00
0.02
0.03
0.05
0.07
0.09
0.10
0.12
0.14
0.15

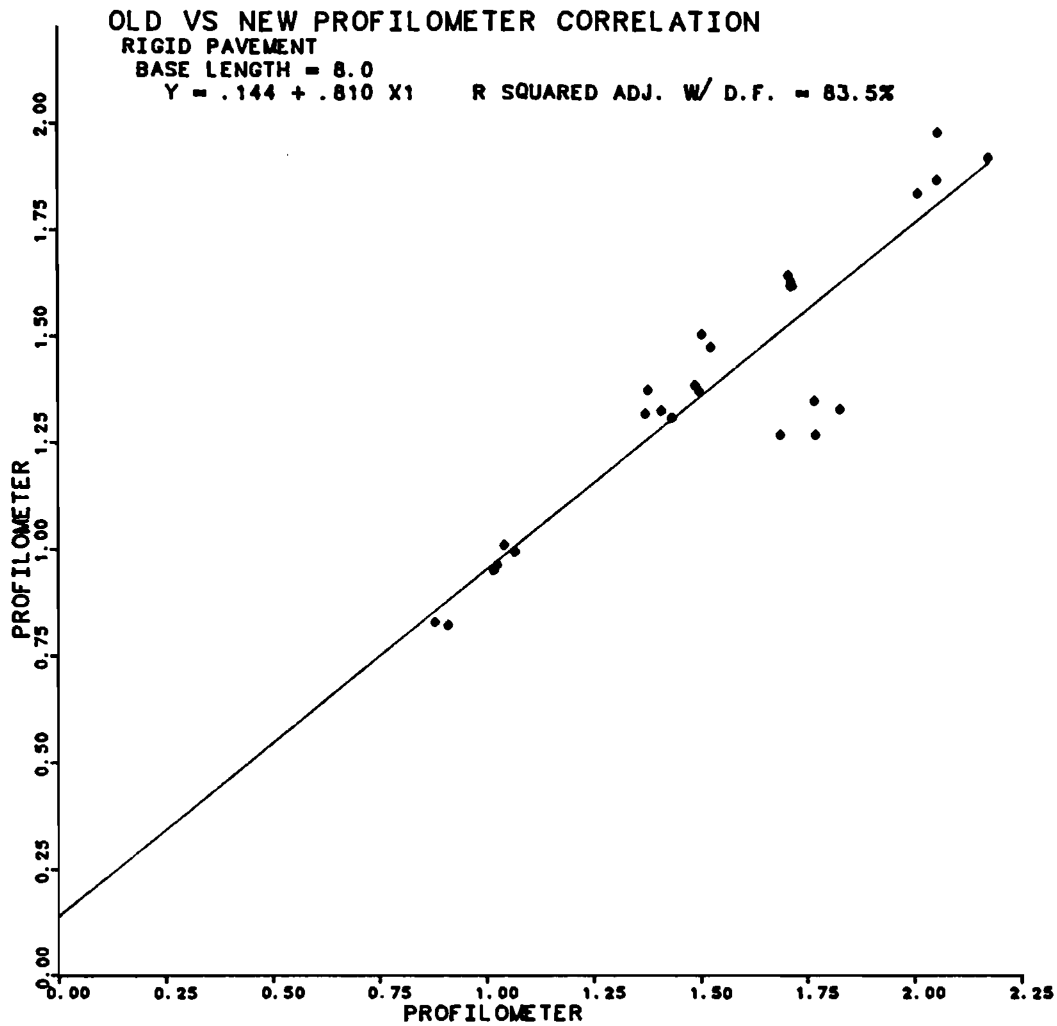

OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 0.5
Y = 36.6 + .369 X1 R SQUARED ADJ. W/ D.F. = 52.0%
OLD PROFILOMETER
0.00
25.41
50.82
76.23
101.64
127.04
152.45
177.86
203.27
NEW PROFILOMETER
0.00
25.41
50.82
76.23
101.64
127.04
152.45
177.86
203.27
228.68

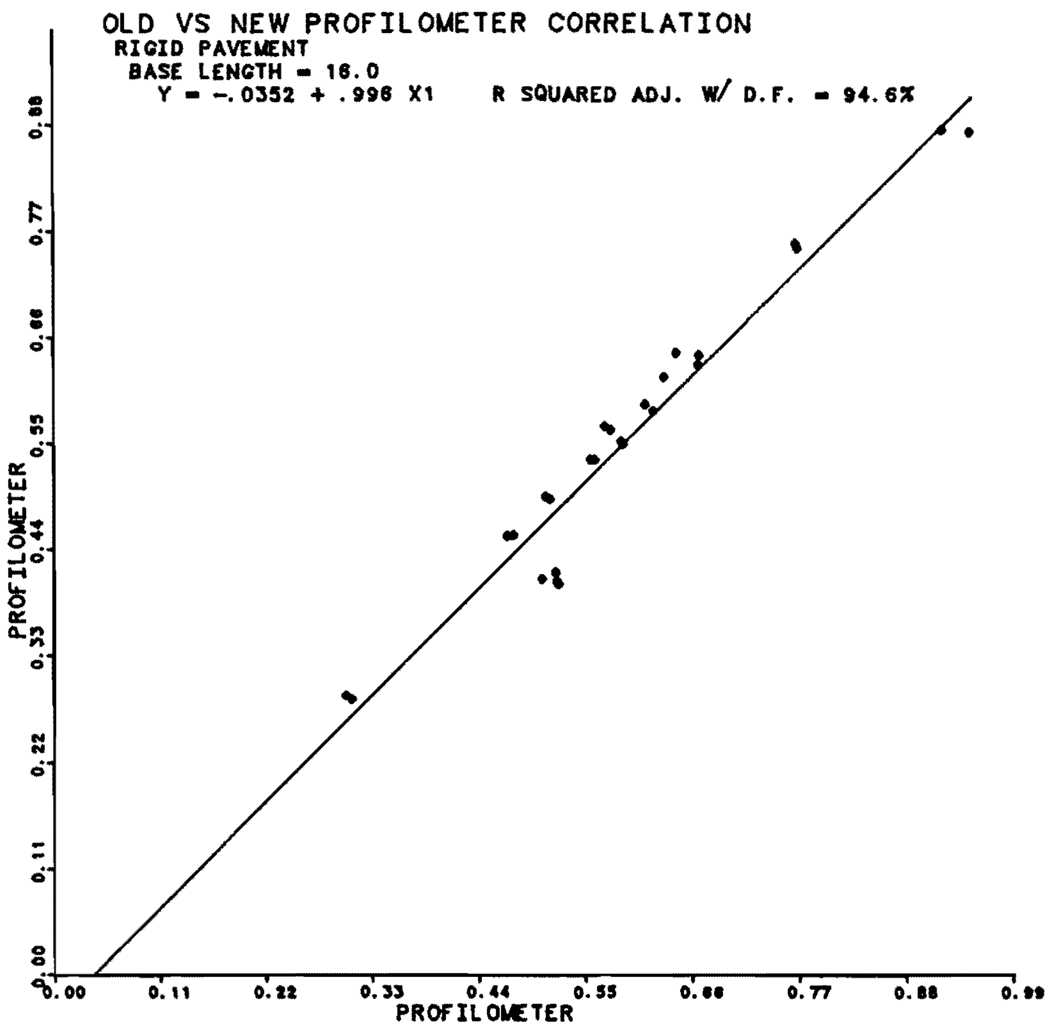

OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 1.0
Y = 16.3 + .256 X1
R SQUARED ADJ. W/ D.F. = 44.6%
OLD PROFILOMETER
NEW PROFILOMETER
0.00
9.01
18.02
27.03
36.04
45.04
54.05
63.06
72.07
81.08


OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 2.0
Y = 4.76 + .339 X1
R SQUARED ADJ. W/ D.F. = 47.3%
PROFILOMETER
0.00
2.55
5.10
7.65
10.20
12.75
15.30
17.85
20.40
22.95
PROFILOMETER
0.00
2.55
5.10
7.65
10.20
12.75
15.30
17.85
20.40

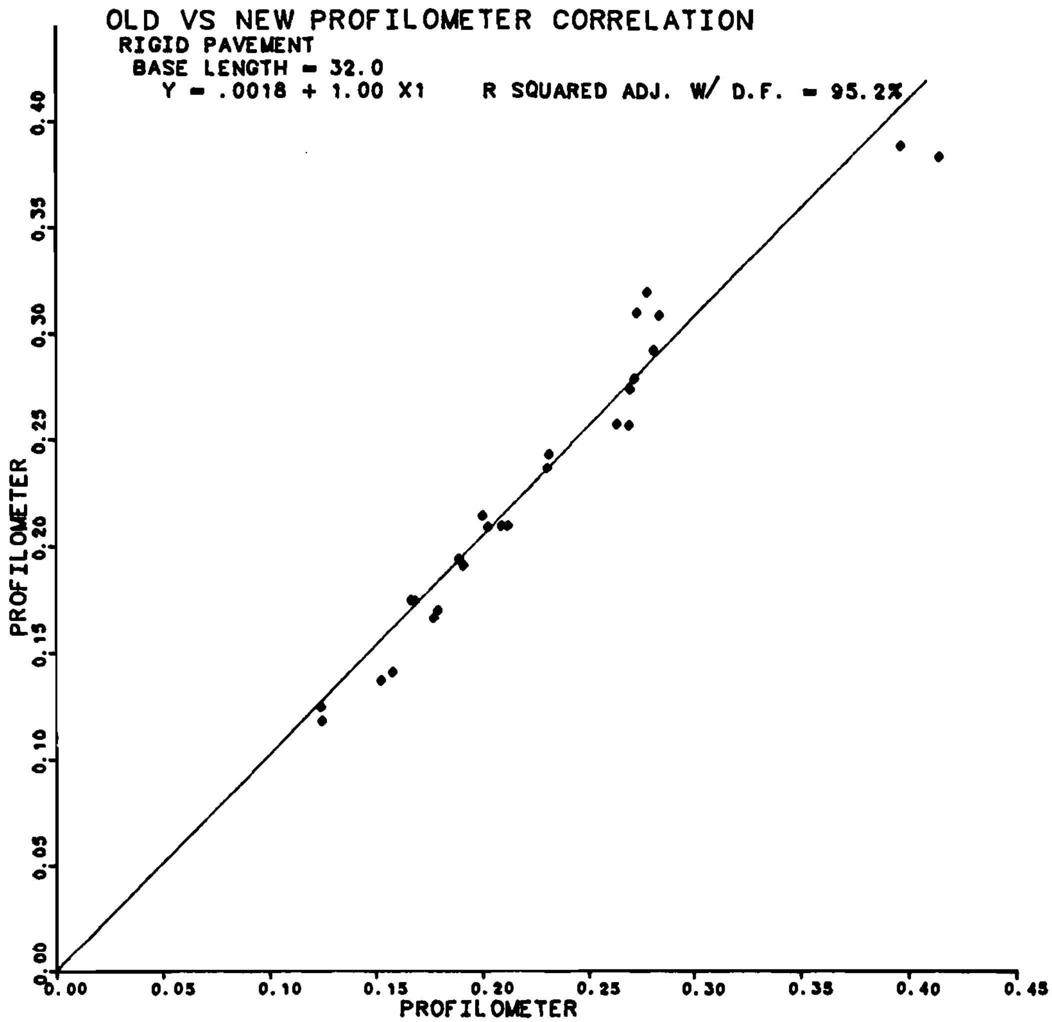


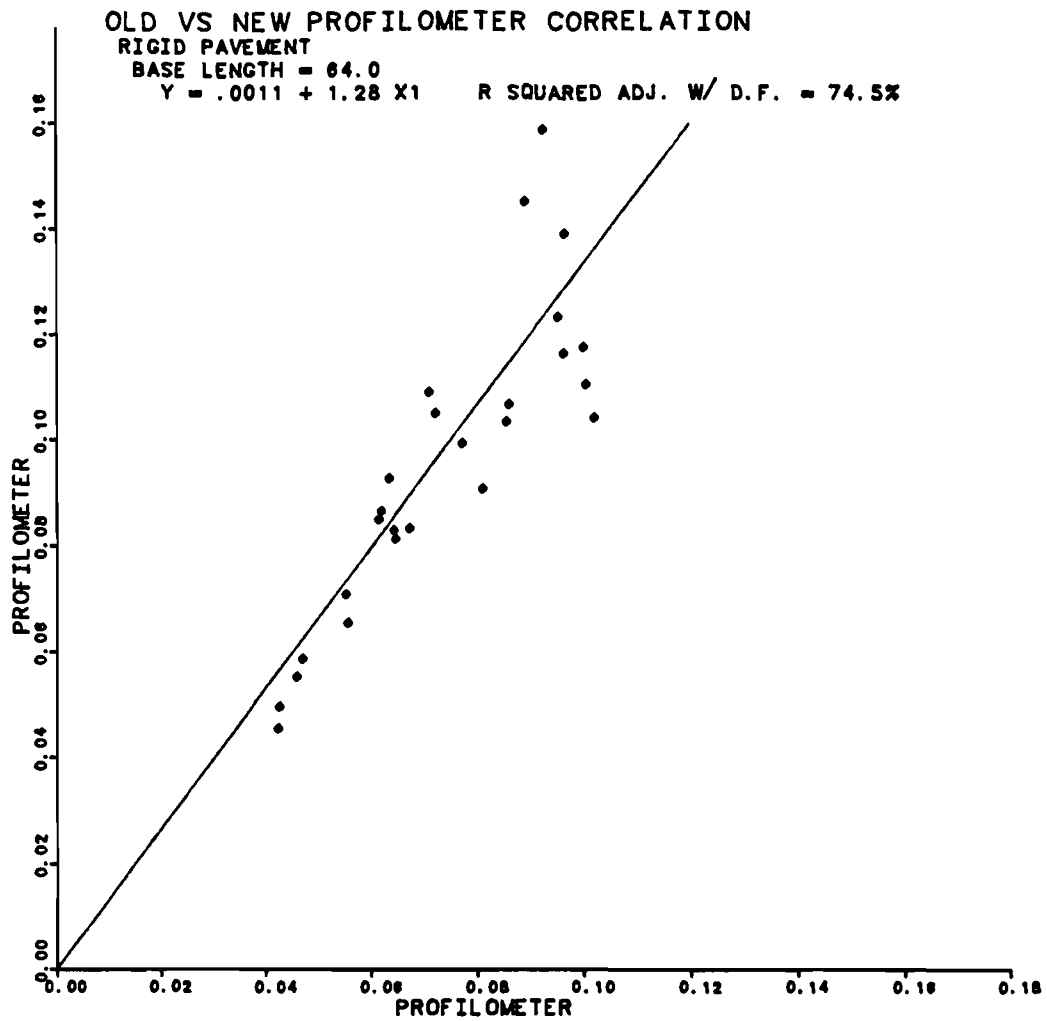
OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 4.0
Y = 1.12 + .552 X1
R SQUARED ADJ. W/ D.F. = 66.3%
PROFILOMETER
0.00
0.73
1.46
2.19
2.92
3.65
4.38
5.11
5.84
6.57
PROFILOMETER

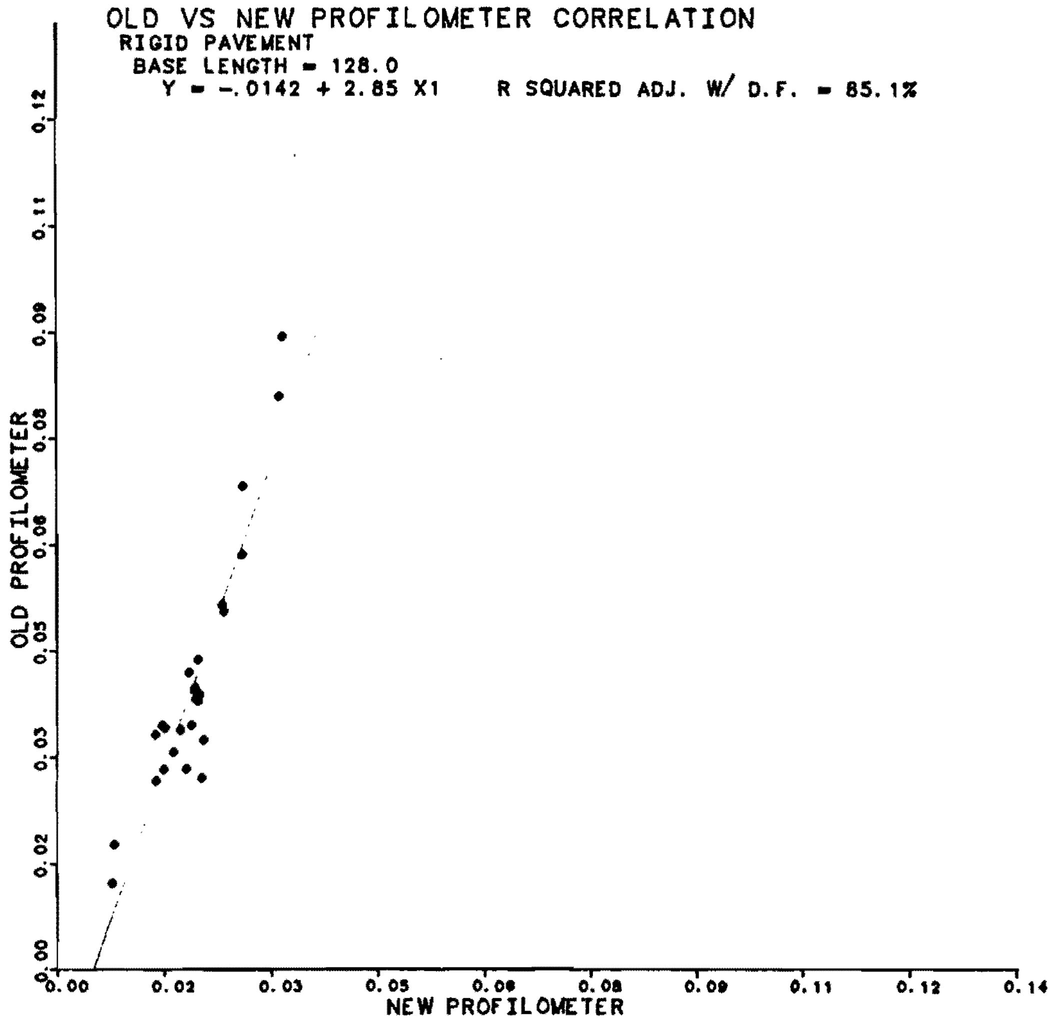

OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 8.0
Y = .144 + .810 X1
R SQUARED ADJ. W/ D.F. = 83.5%
PROFILOMETER
PROFILOMETER
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25



OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 16.0
Y = -.0352 + .996 X1   R SQUARED ADJ. W/ D.F. = 94.6%
PROFILOMETER
PROFILOMETER
0.00
0.11
0.22
0.33
0.44
0.55
0.66
0.77
0.88
0.99

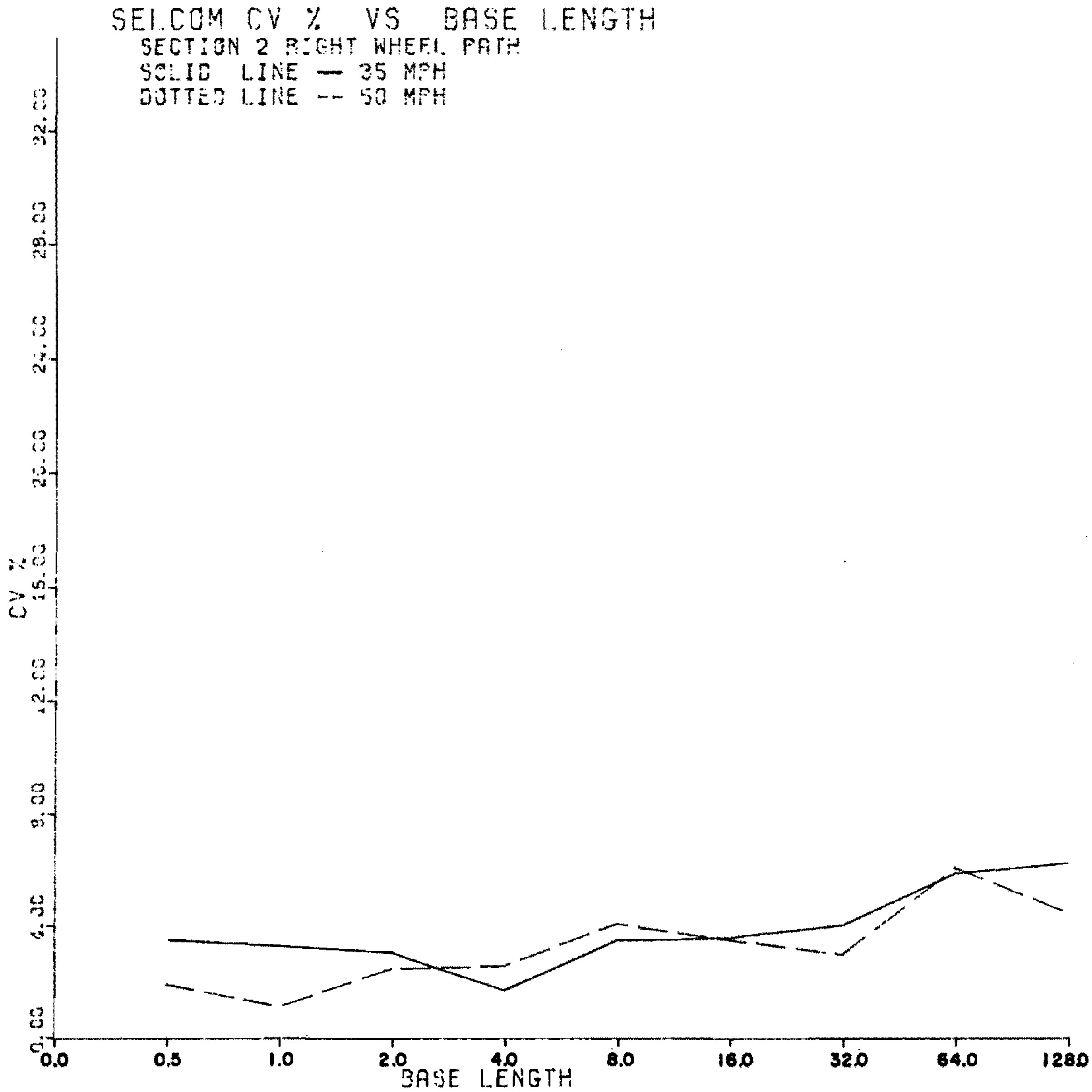

OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 32.0
Y = .0018 + 1.00 X1
R SQUARED ADJ. W/ D.F. = 95.2%
PROFILOMETER
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
PROFILOMETER

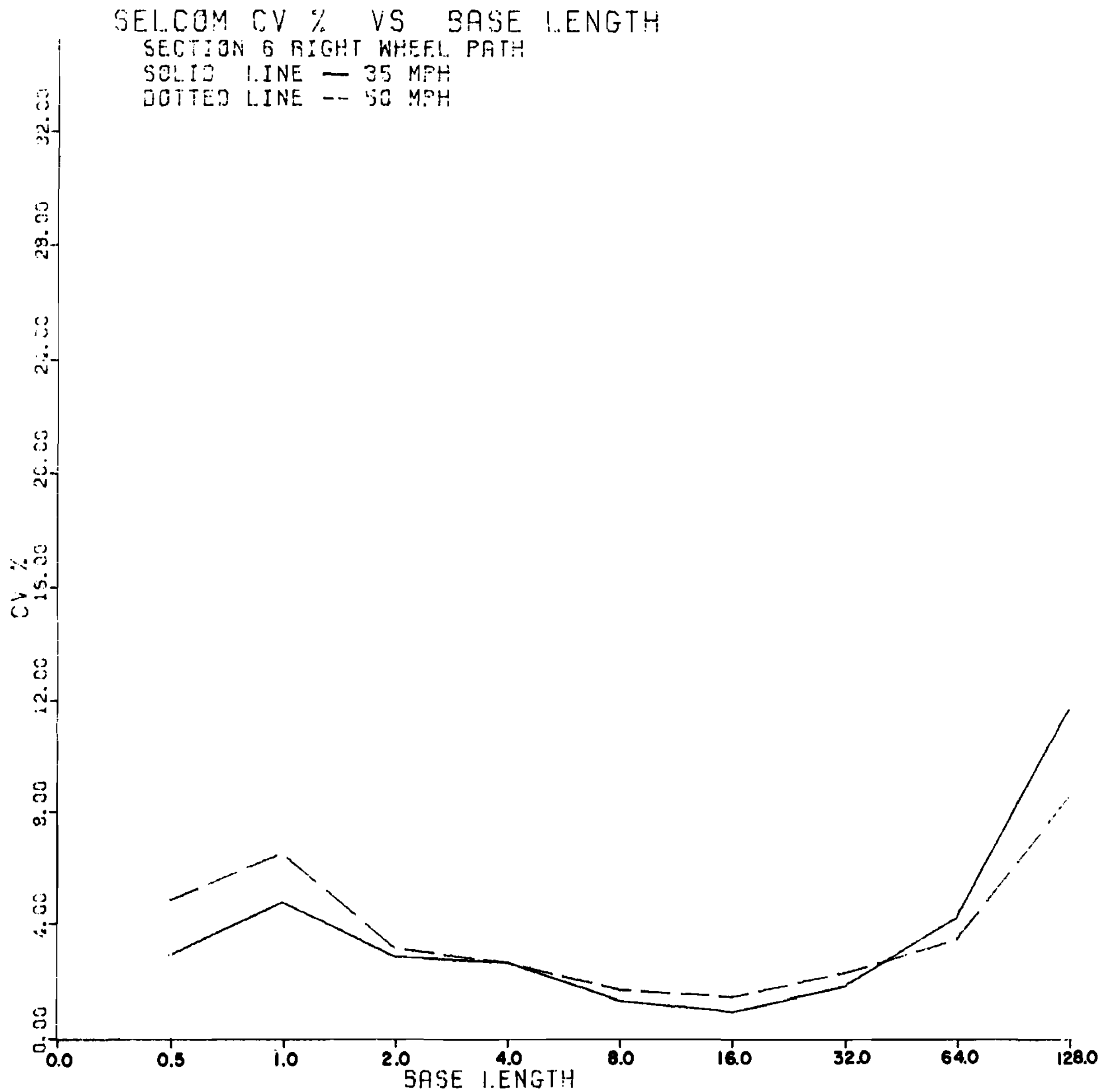

OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 64.0
Y = .0011 + 1.28 X1   R SQUARED ADJ. W/ D.F. = 74.5%
PROFILOMETER
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
PROFILOMETER


OLD VS NEW PROFILOMETER CORRELATION
RIGID PAVEMENT
BASE LENGTH = 128.0
Y = -.0142 + 2.85 X1   R SQUARED ADJ. W/ D.F. = 85.1%
OLD PROFILOMETER
NEW PROFILOMETER

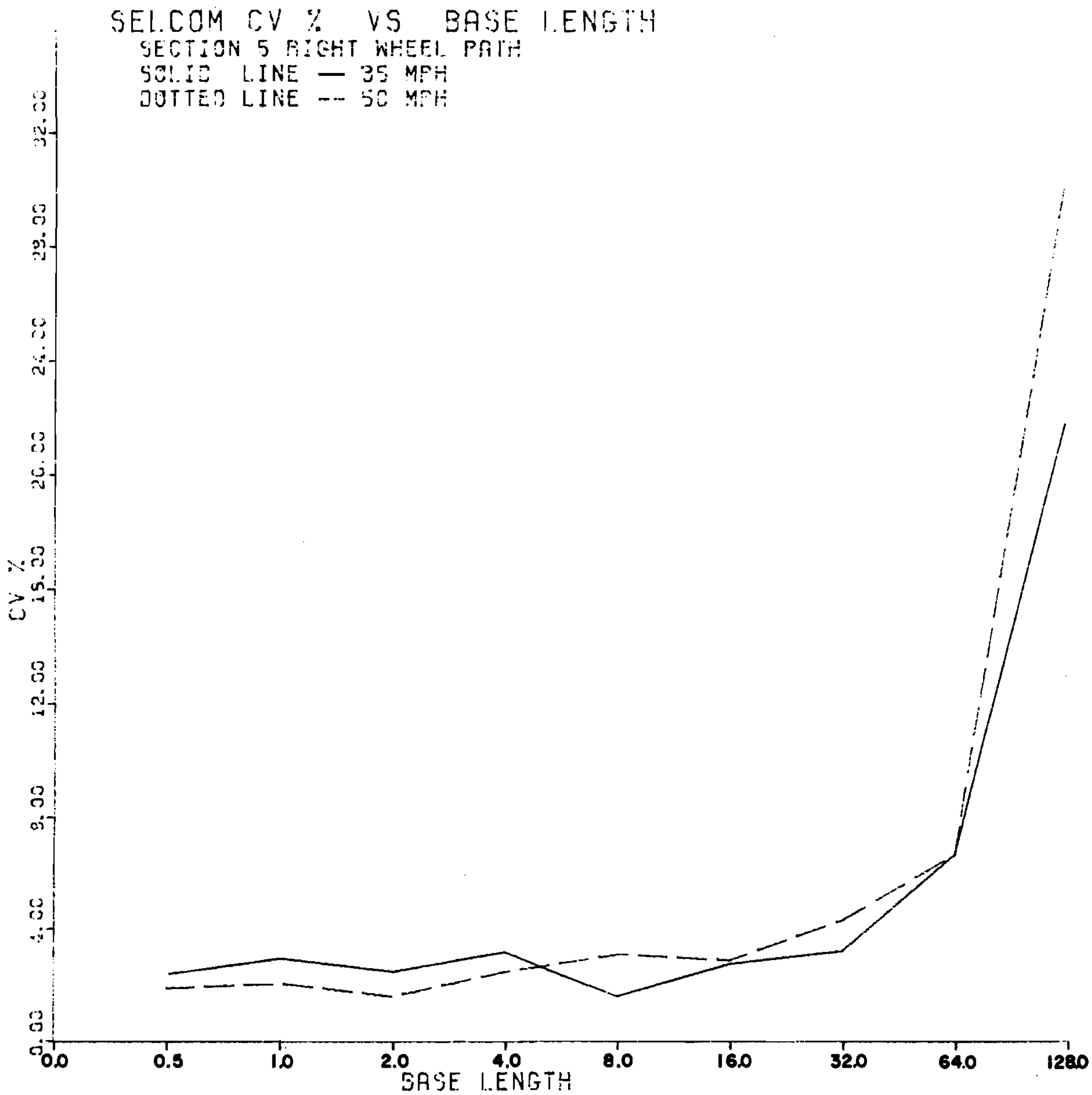
APPENDIX B

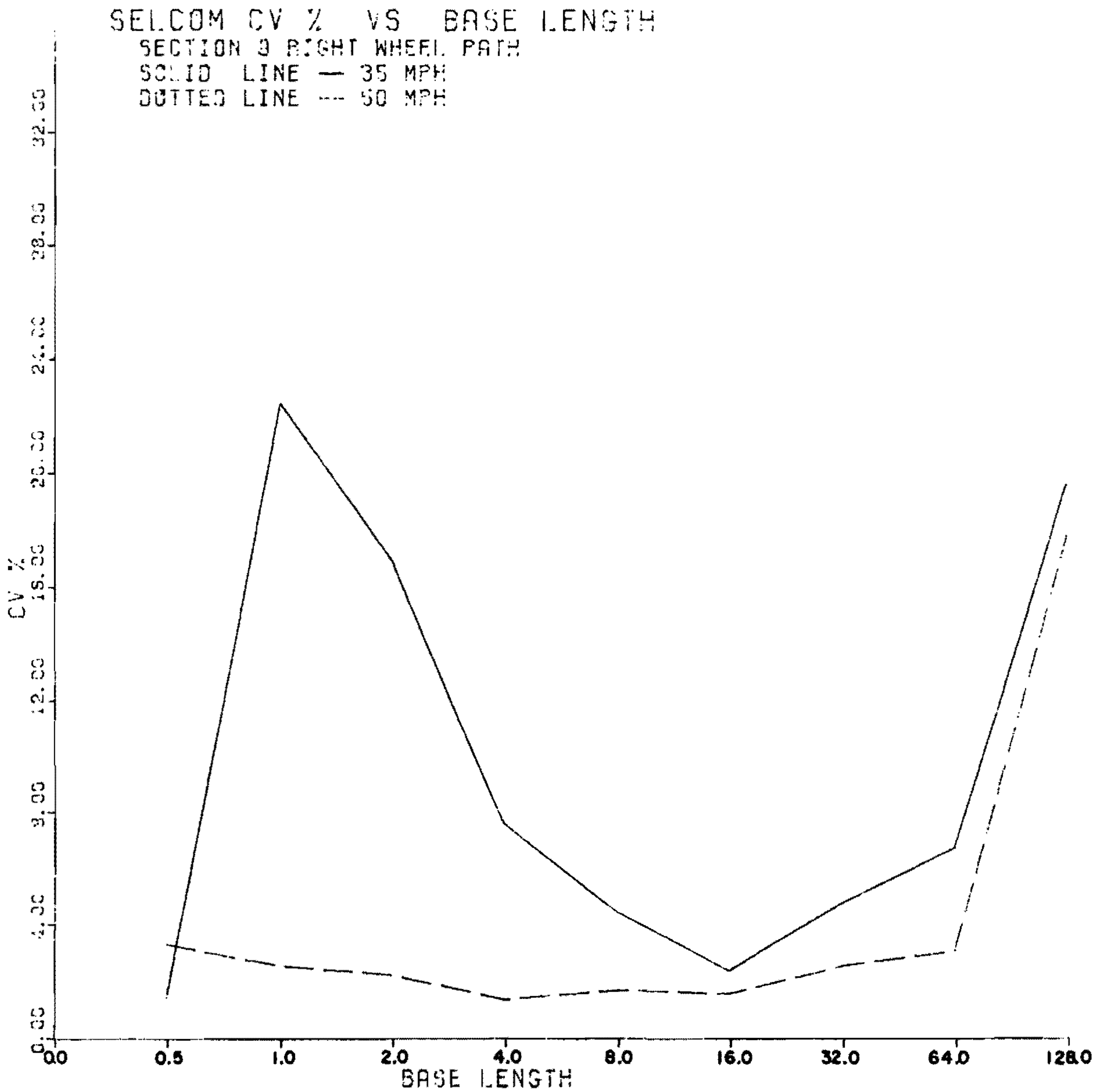
COEFFICIENT OF VARIATION VERSUS BASE LENGTHS FOR SECTIONS 2, 6, 5, 9, 7 AND 32

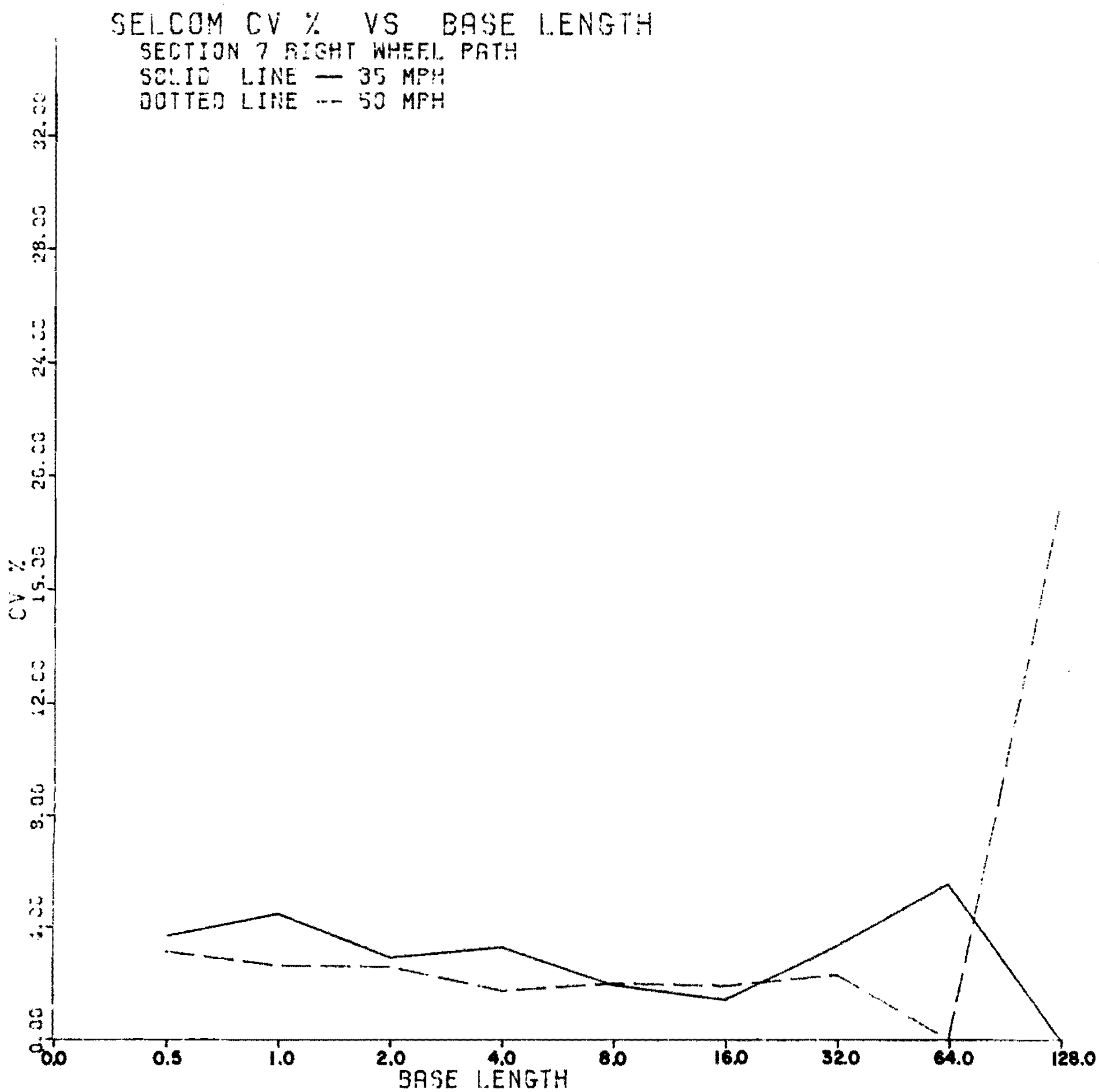

SELCOM CV % VS BASE LENGTH
SECTION 2 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

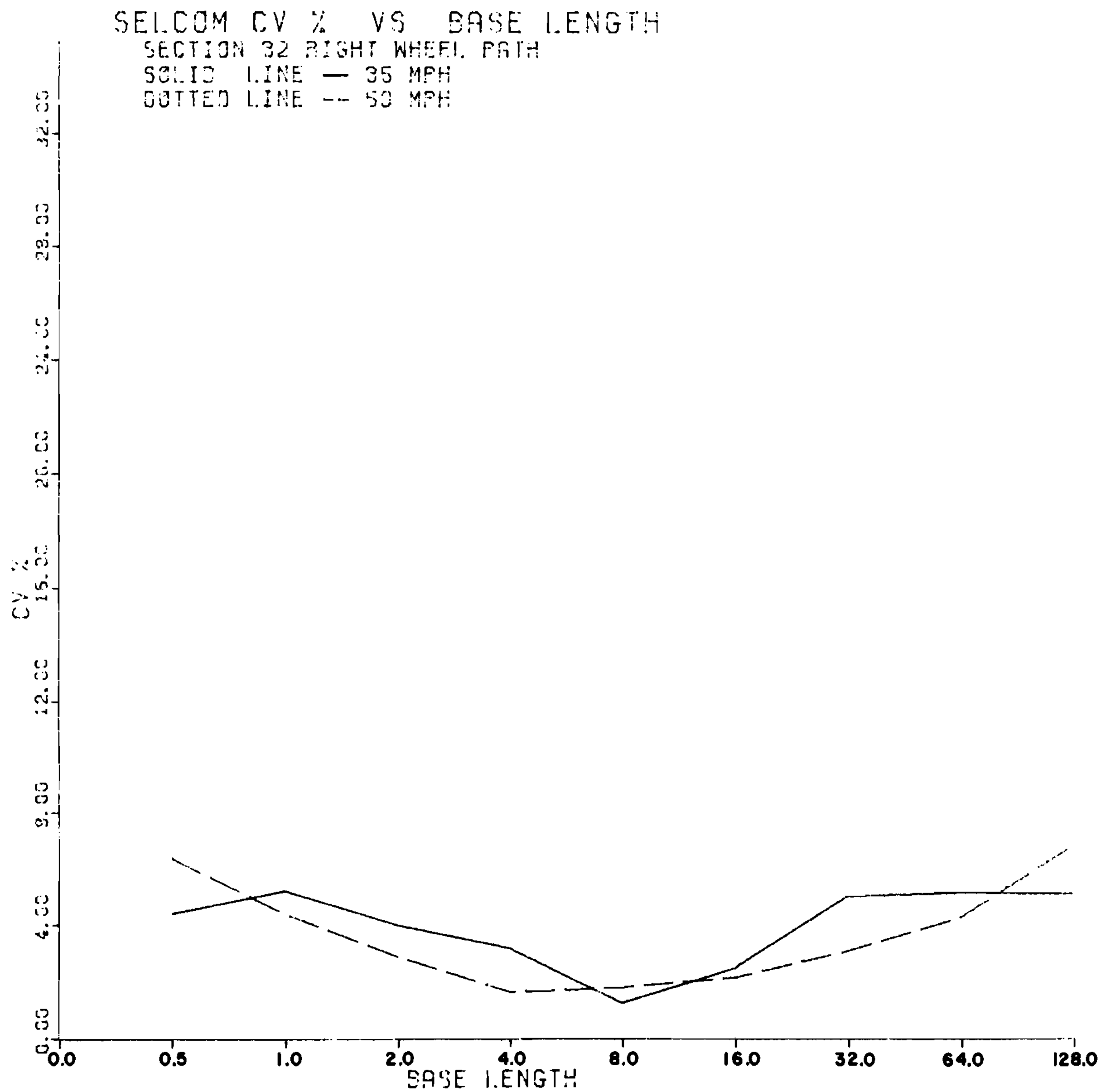

SELCOM CV % VS BASE LENGTH
SECTION 6 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

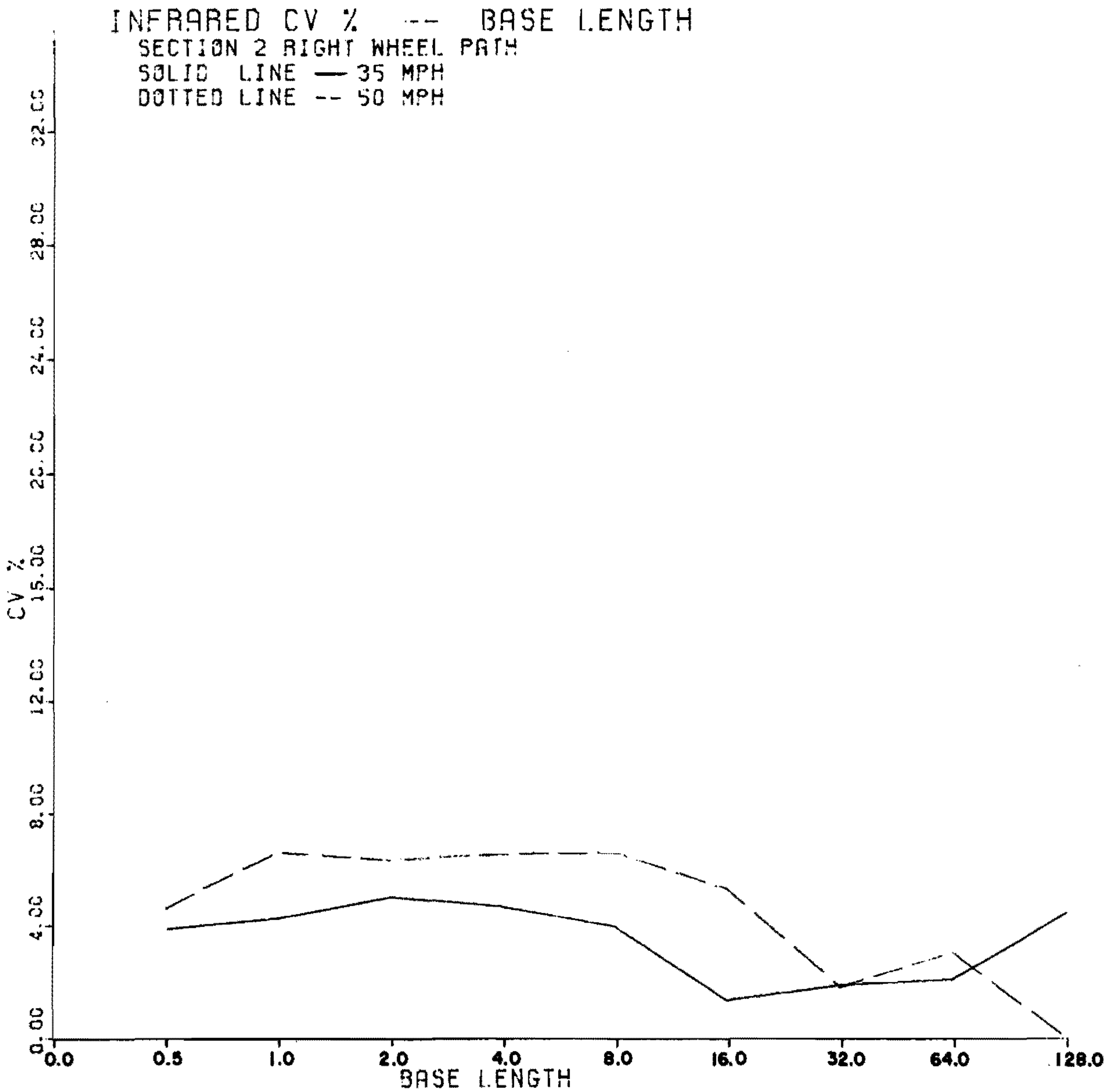
010 067


SELCOM CV % VS BASE LENGTH
SECTION 5 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

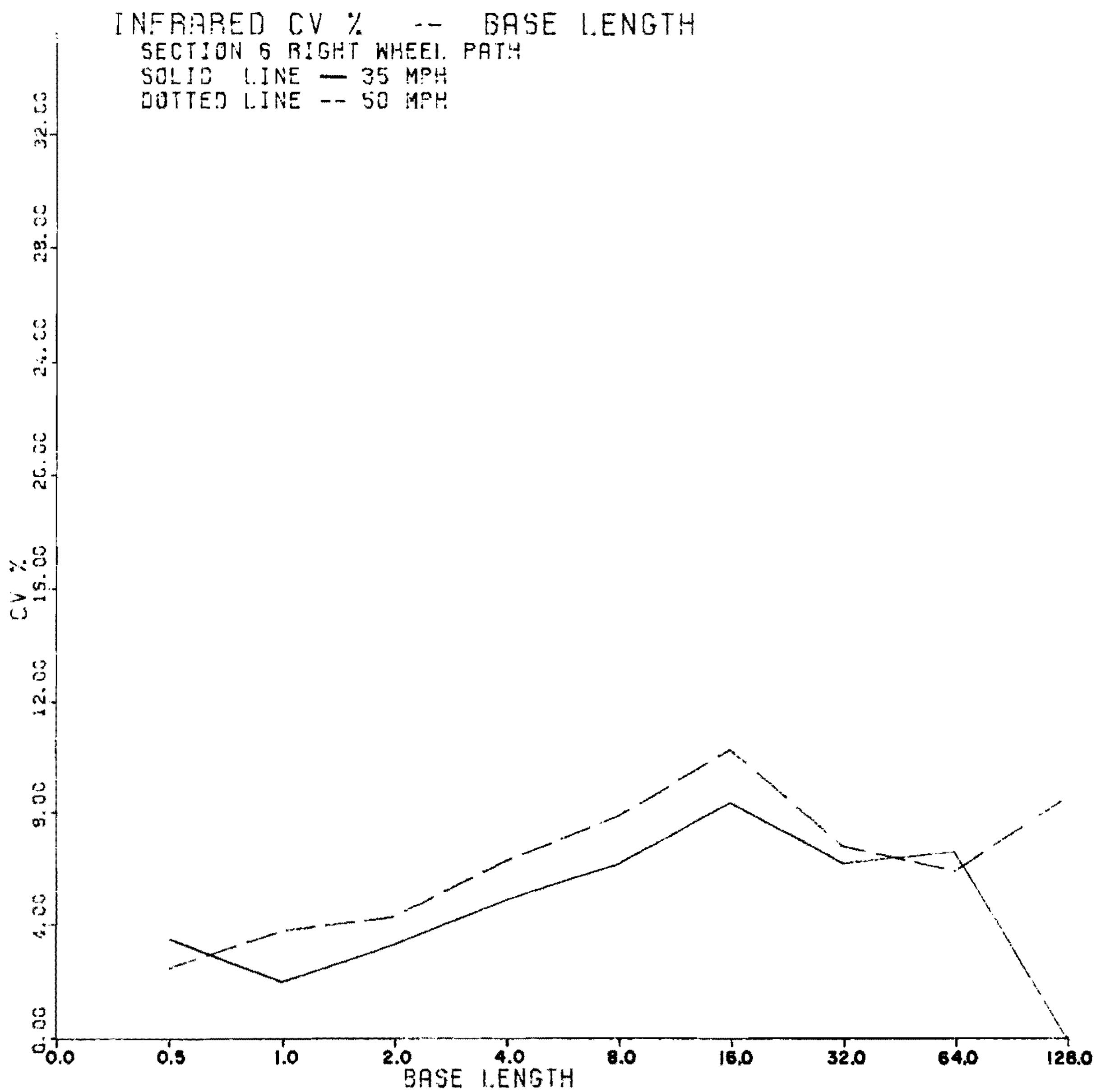

SELCOM CV % VS BASE LENGTH
SECTION 3 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

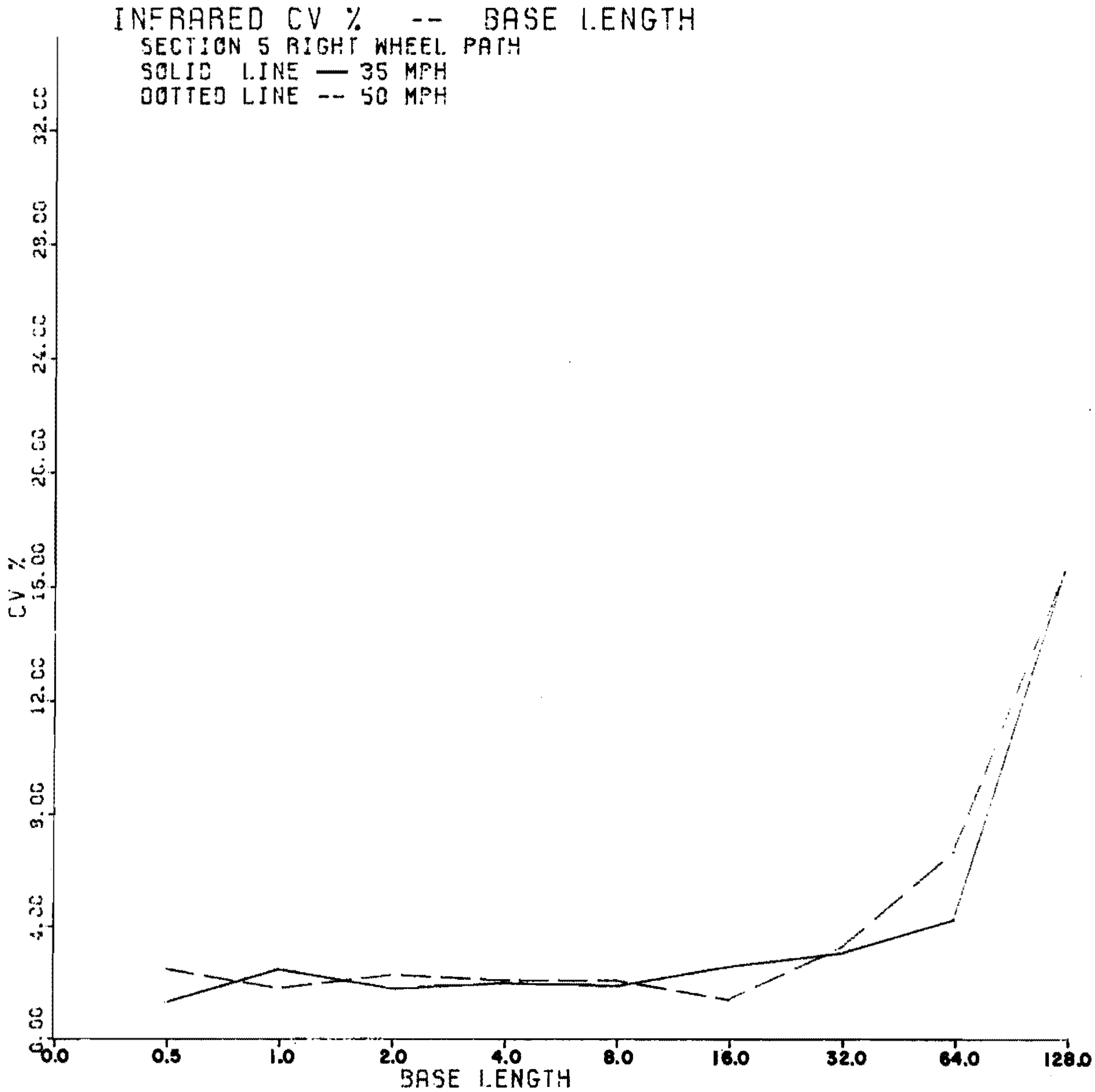

SELCOM CV % VS BASE LENGTH
SECTION 7 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
BASE LENGTH
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0


SELCOM CV % VS BASE LENGTH
SECTION 32 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

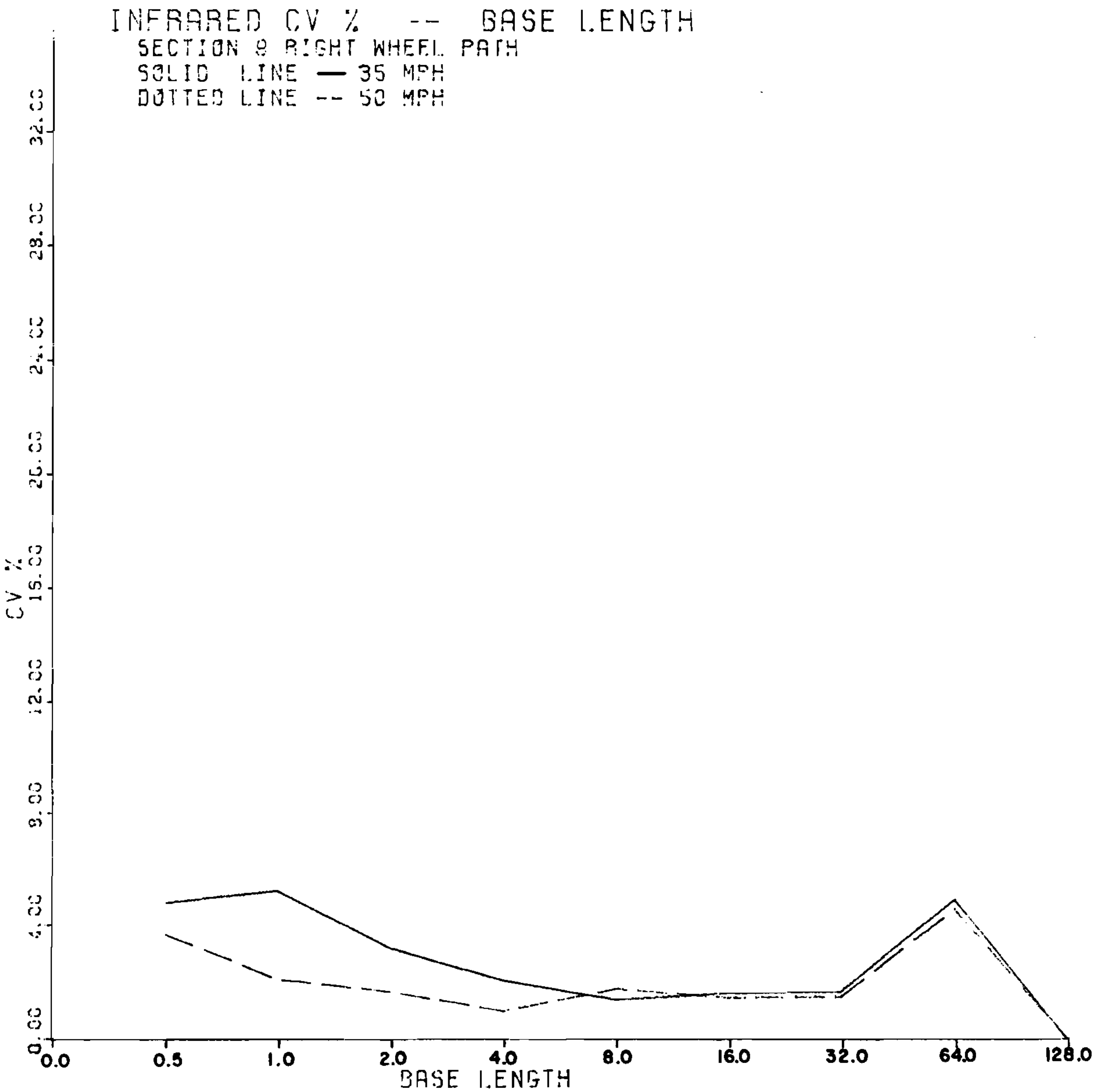

INFRARED CV % -- BASE LENGTH
SECTION 2 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

010 072

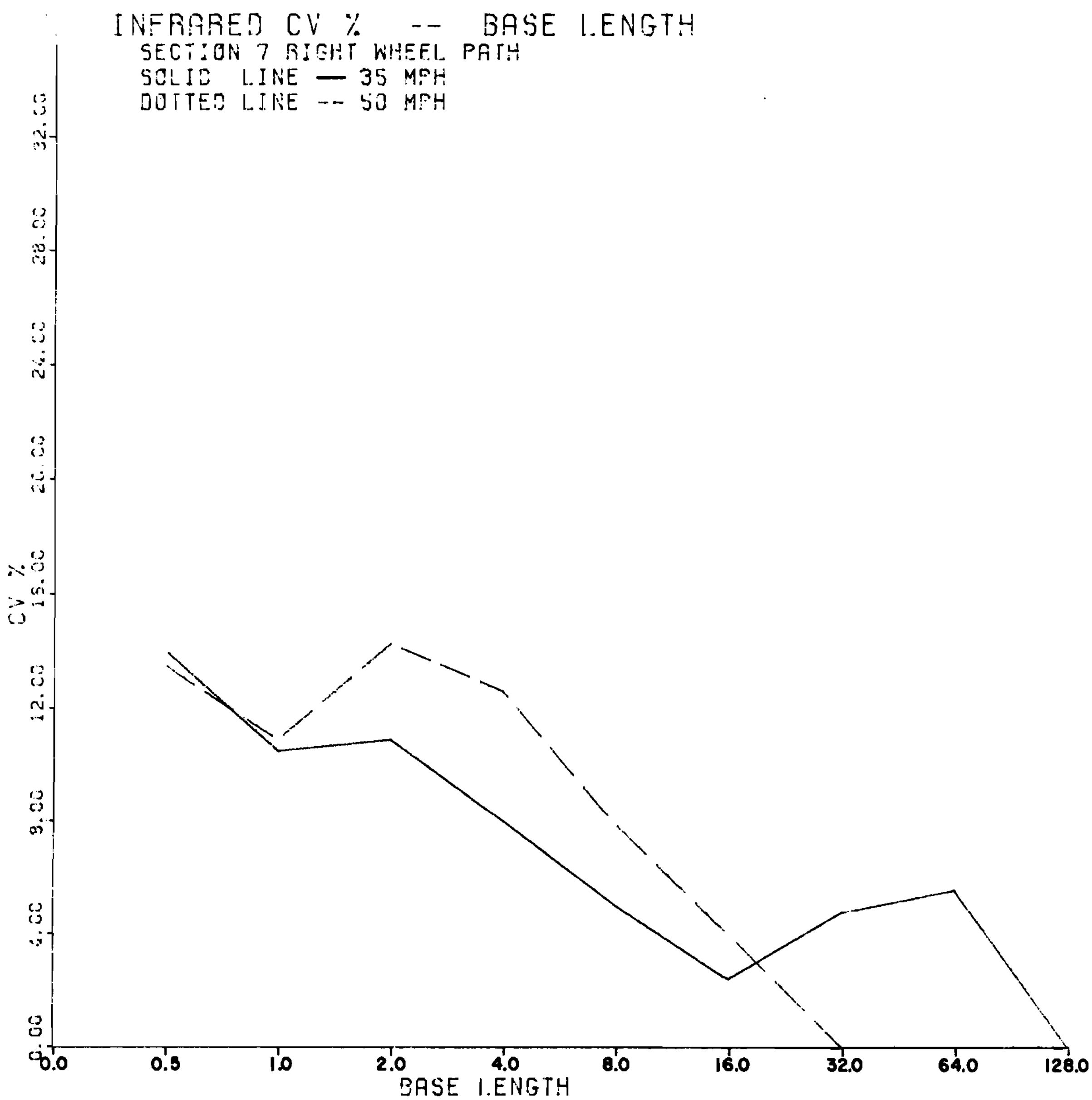

INFRARED CV % -- BASE LENGTH
SECTION 6 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

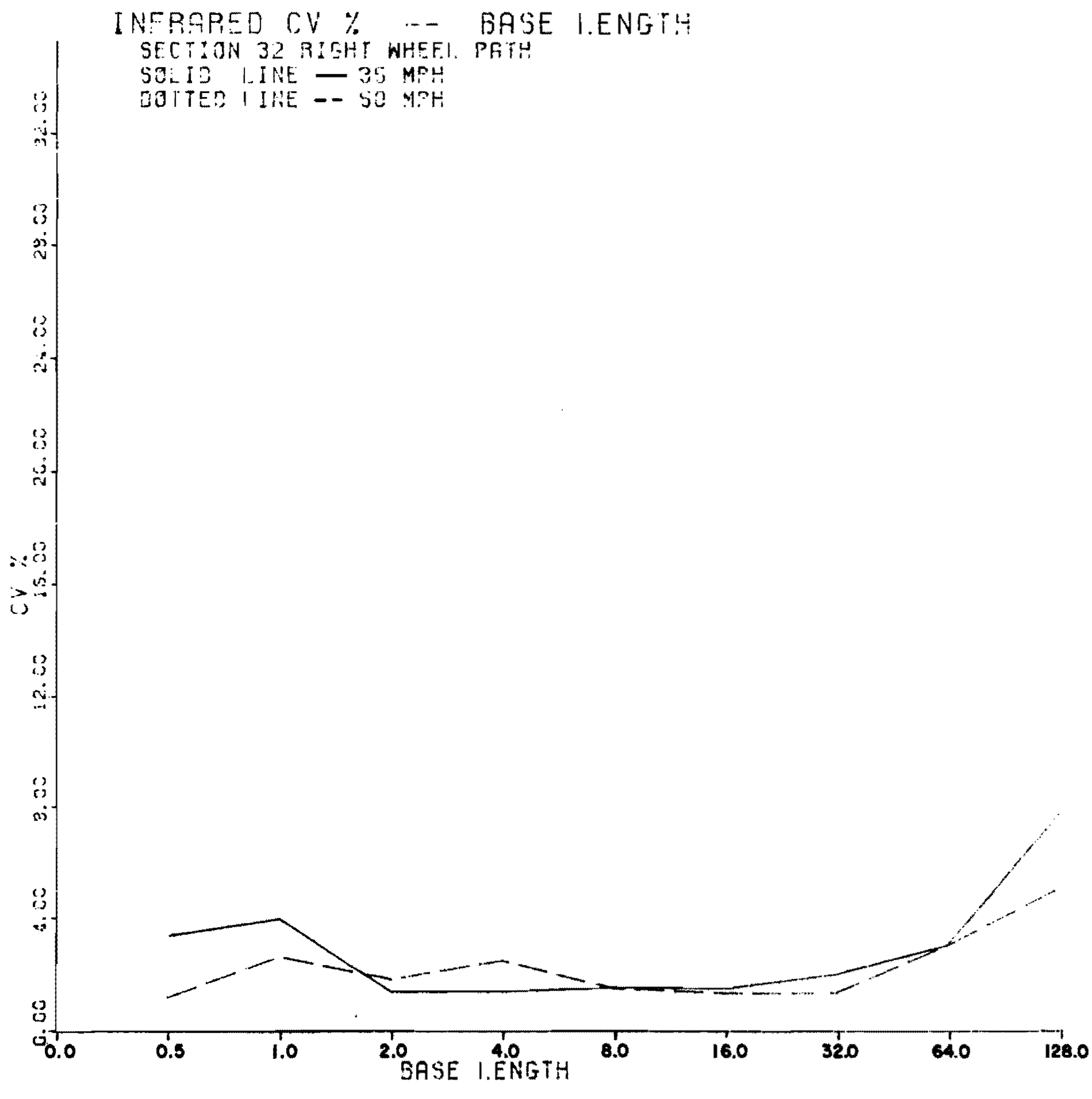

INFRARED CV % -- BASE LENGTH
SECTION 5 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
9.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

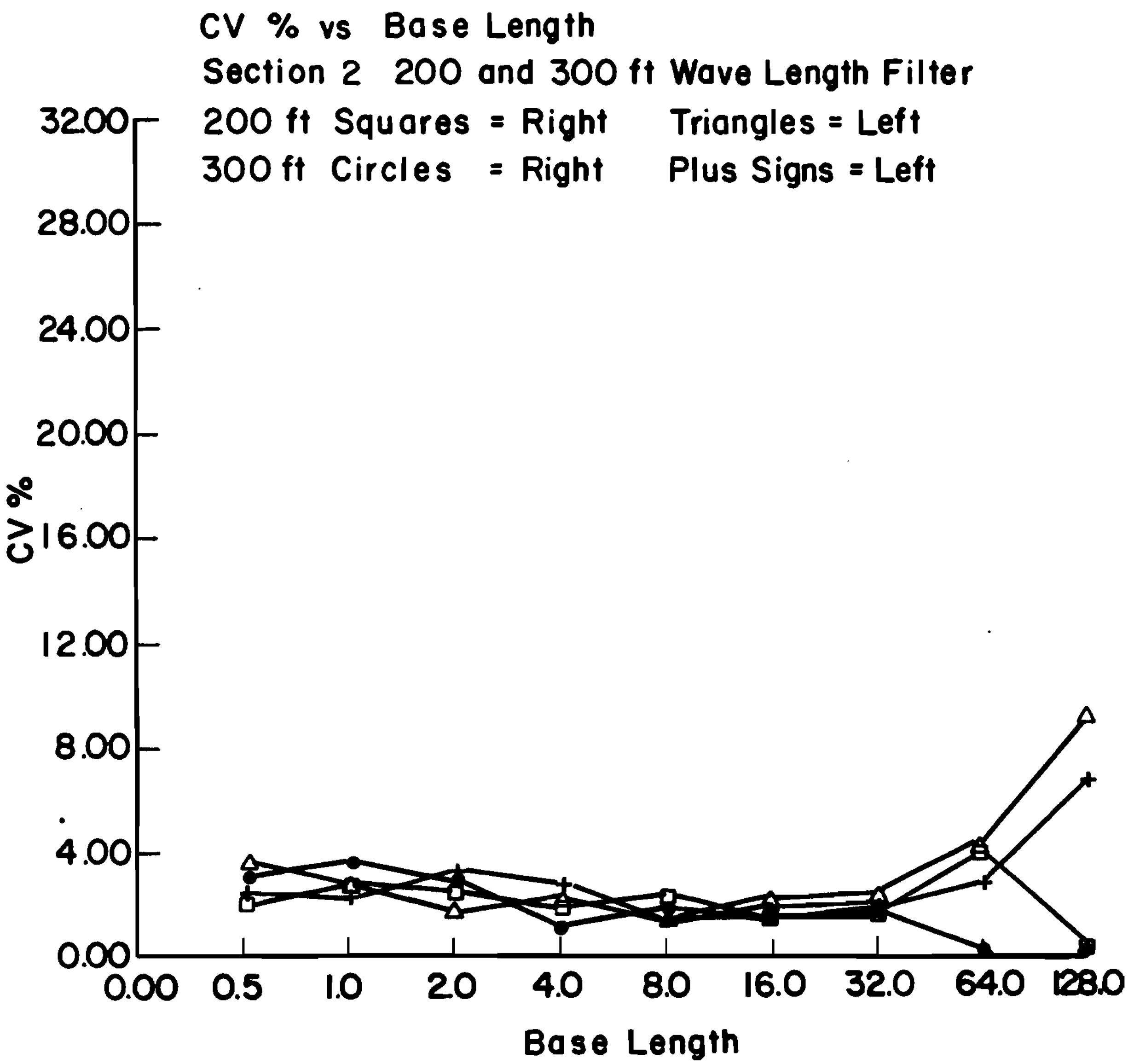
010 074

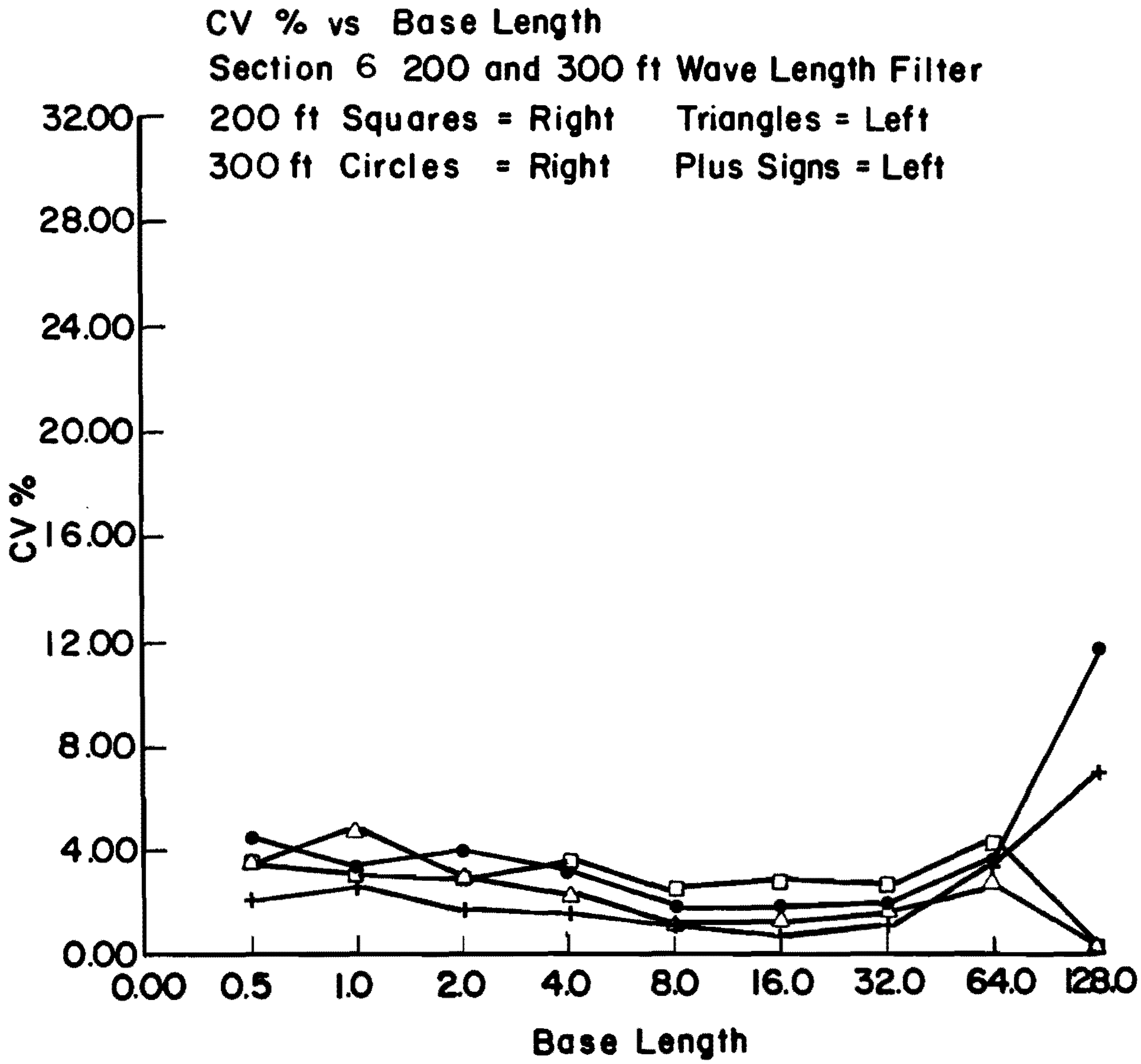


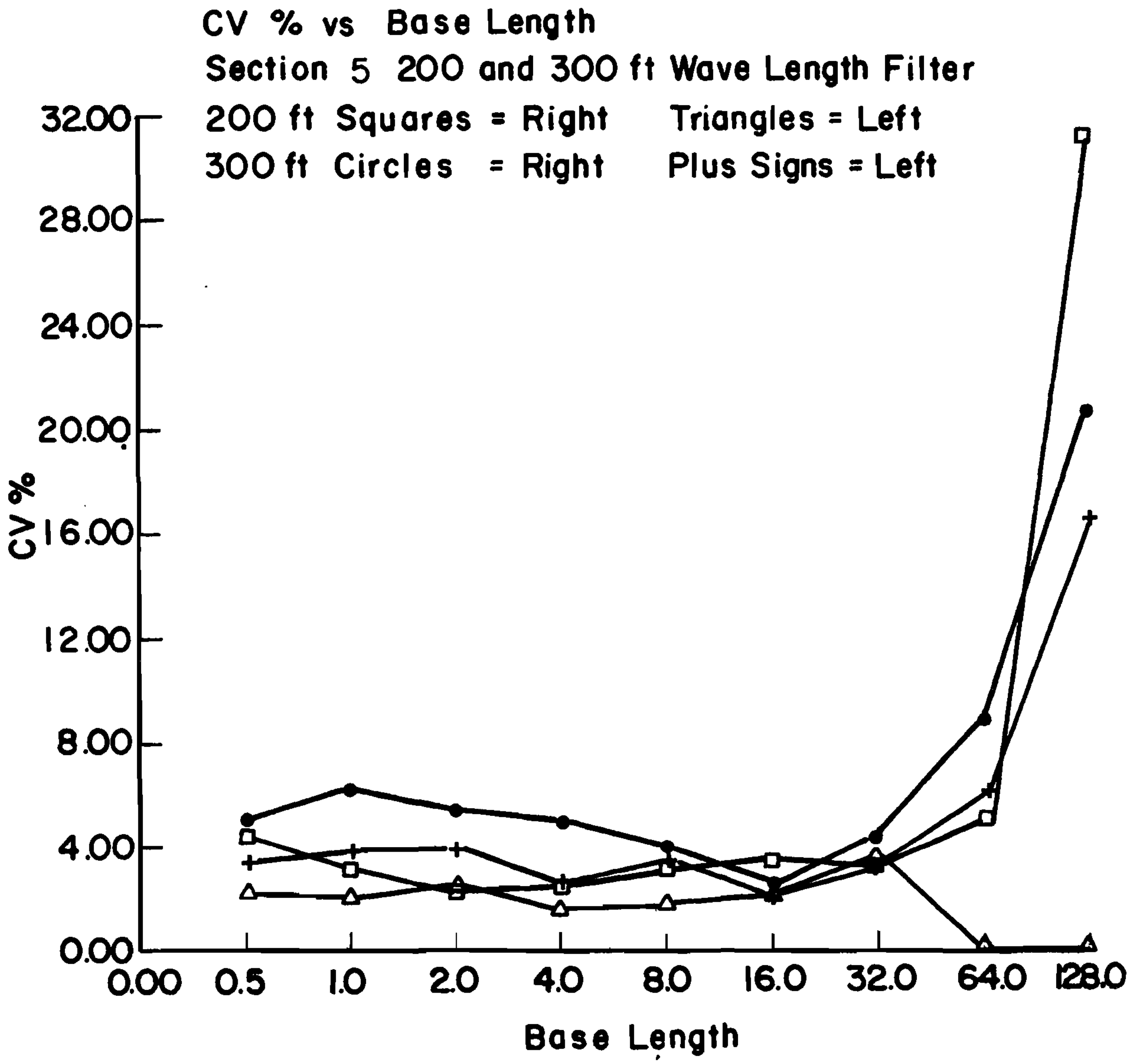
INFRARED CV % -- BASE LENGTH
SECTION 8 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH


INFRARED CV % -- BASE LENGTH
SECTION 7 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

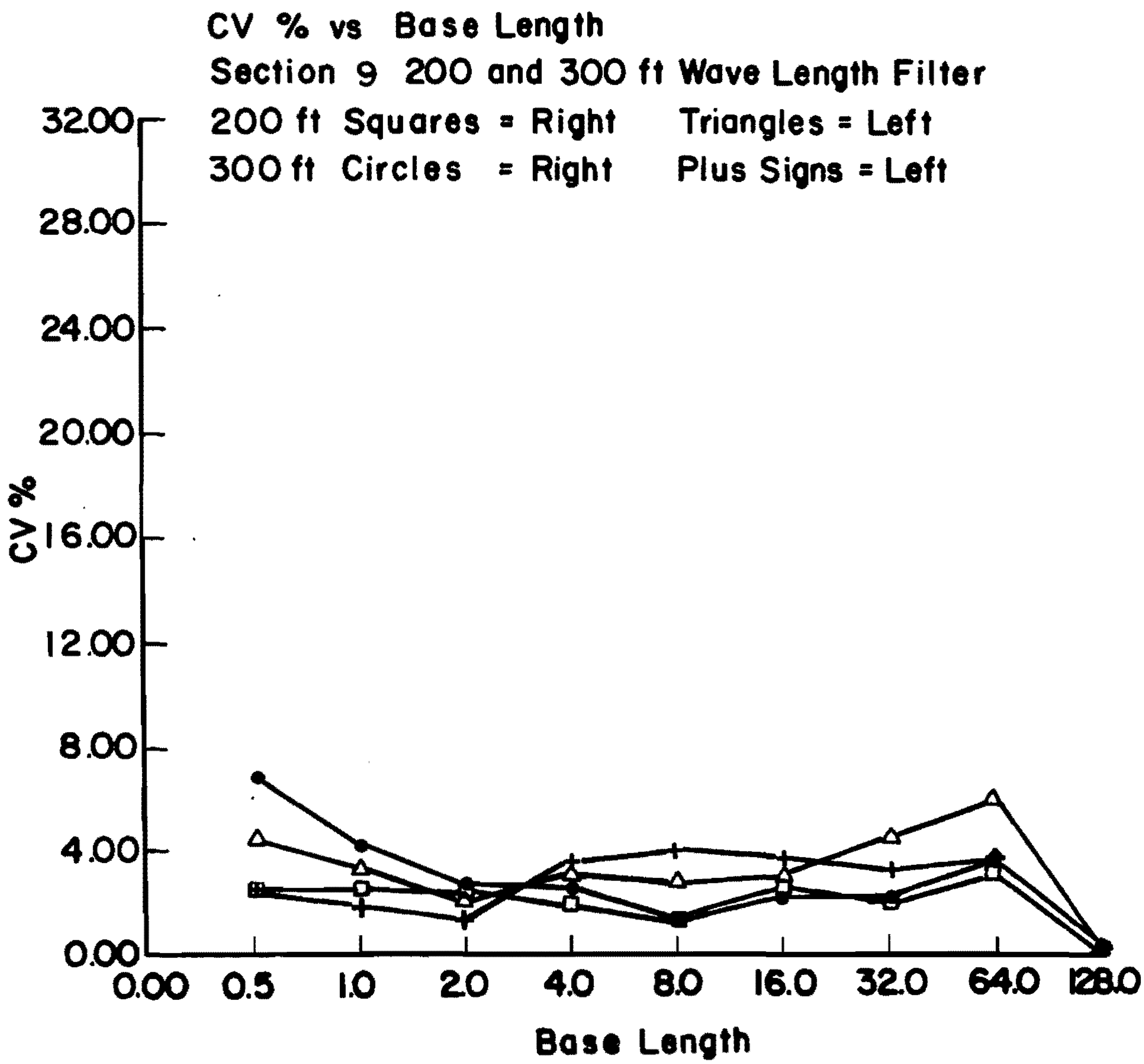

INFRARED CV % -- BASE LENGTH
SECTION 32 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
CV %
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

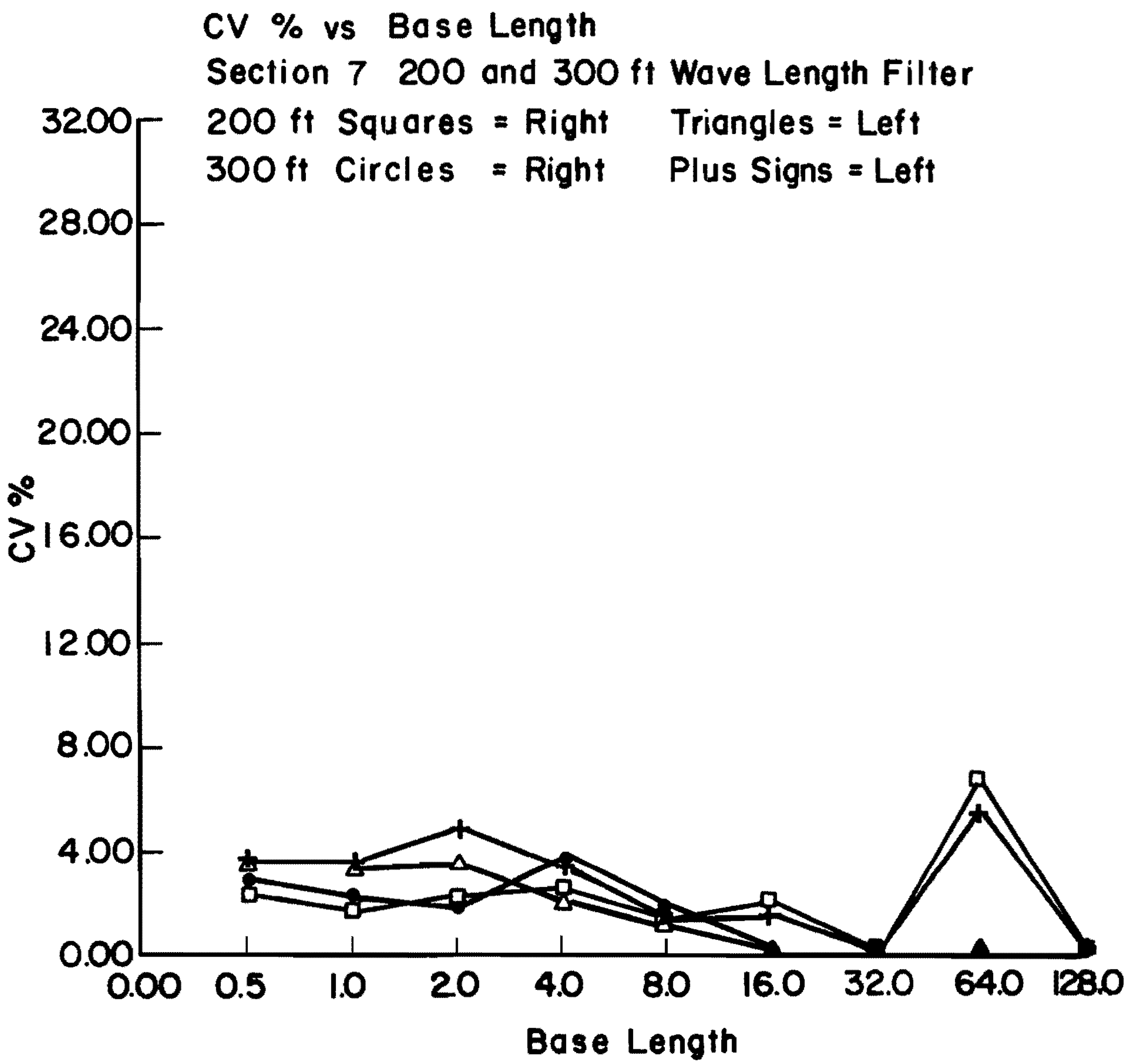

CV % vs Base Length
Section 2 200 and 300 ft Wave Length Filter
200 ft Squares = Right Triangles = Left
300 ft Circles = Right Plus Signs = Left
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
CV %
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length


CV % vs Base Length
Section 6 200 and 300 ft Wave Length Filter
200 ft Squares = Right Triangles = Left
300 ft Circles = Right Plus Signs = Left
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
CV %
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

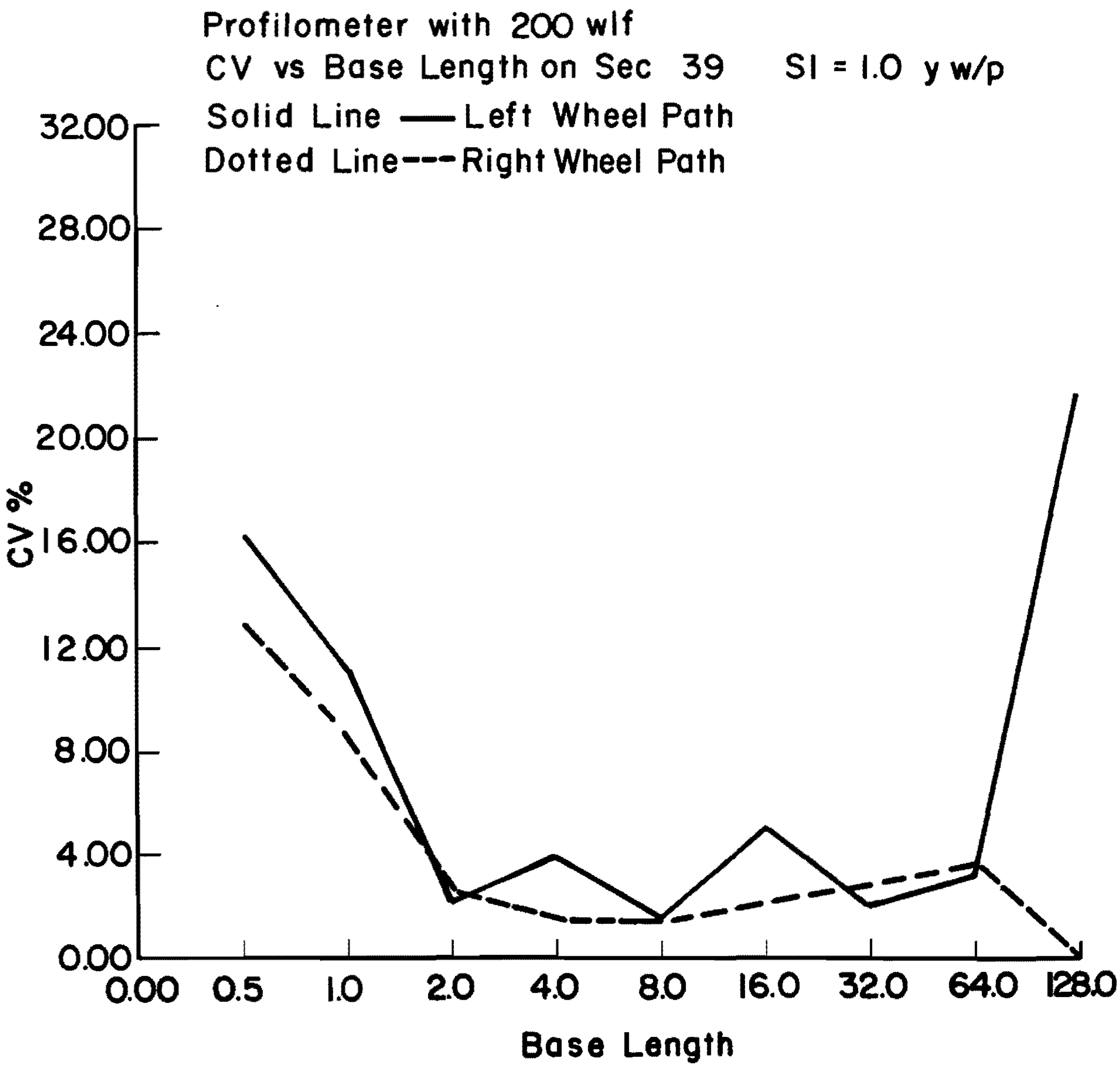


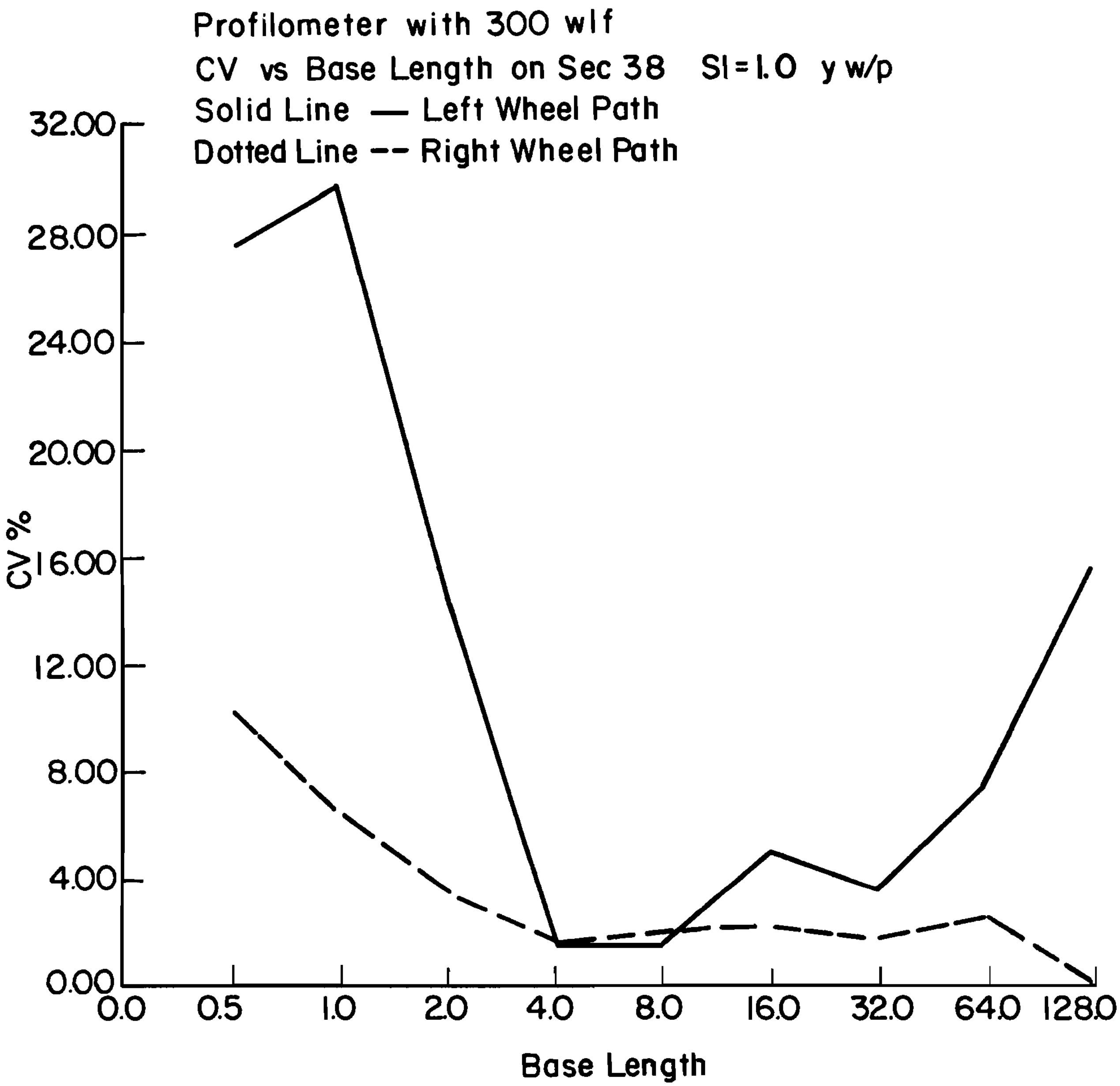
CV % vs Base Length
Section 5 200 and 300 ft Wave Length Filter
200 ft Squares = Right Triangles = Left
300 ft Circles = Right Plus Signs = Left
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
CV %
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length


CV % vs Base Length
Section 9 200 and 300 ft Wave Length Filter
200 ft Squares = Right Triangles = Left
300 ft Circles = Right Plus Signs = Left
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
CV %
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length


CV % vs Base Length
Section 7 200 and 300 ft Wave Length Filter
200 ft Squares = Right Triangles = Left
300 ft Circles = Right Plus Signs = Left
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
CV %
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

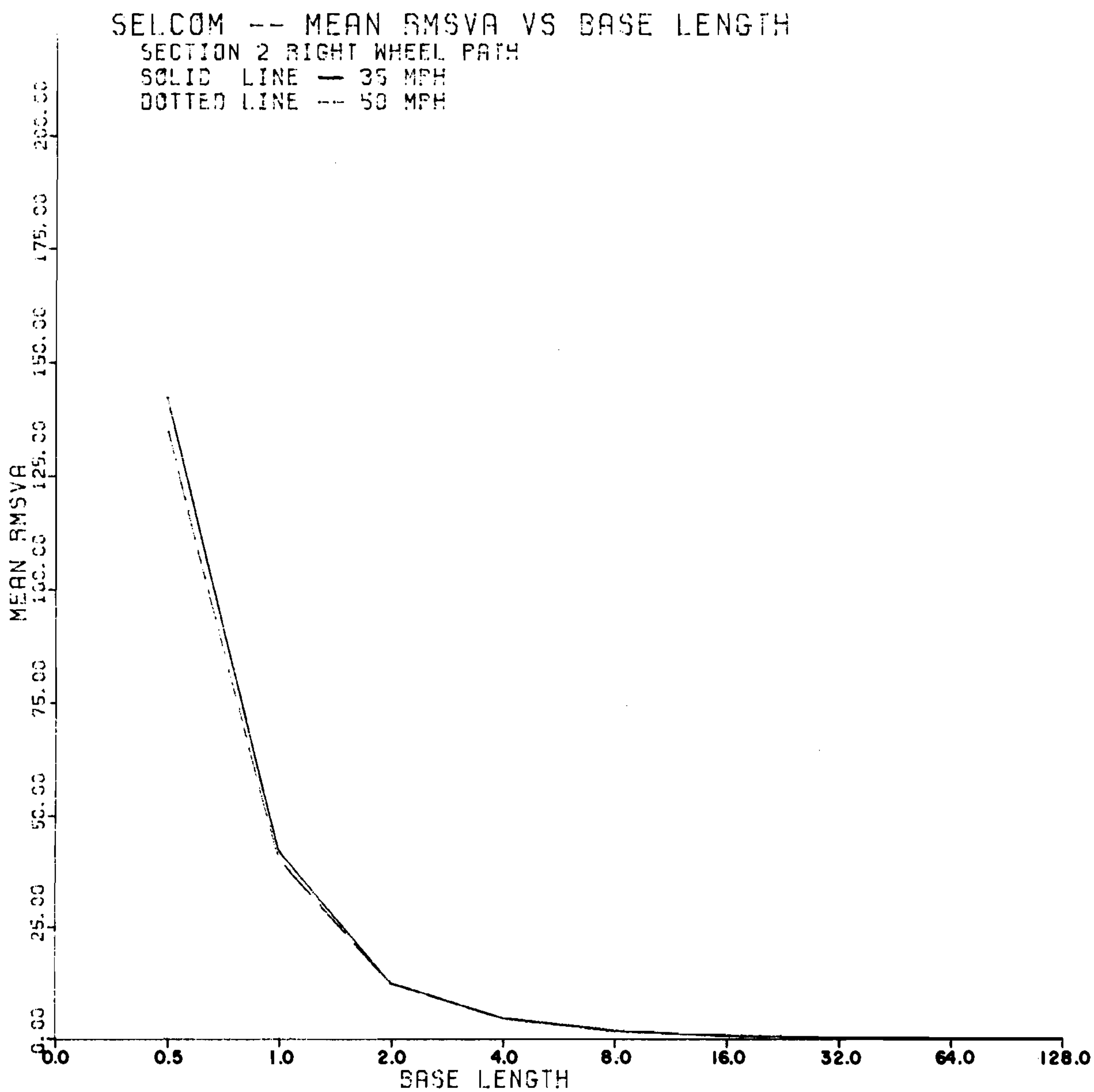
010 100


Profilometer with 200 wlf
CV vs Base Length on Sec 39 SI = 1.0 y w/p
Solid Line —— Left Wheel Path
Dotted Line --- Right Wheel Path
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
CV %
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

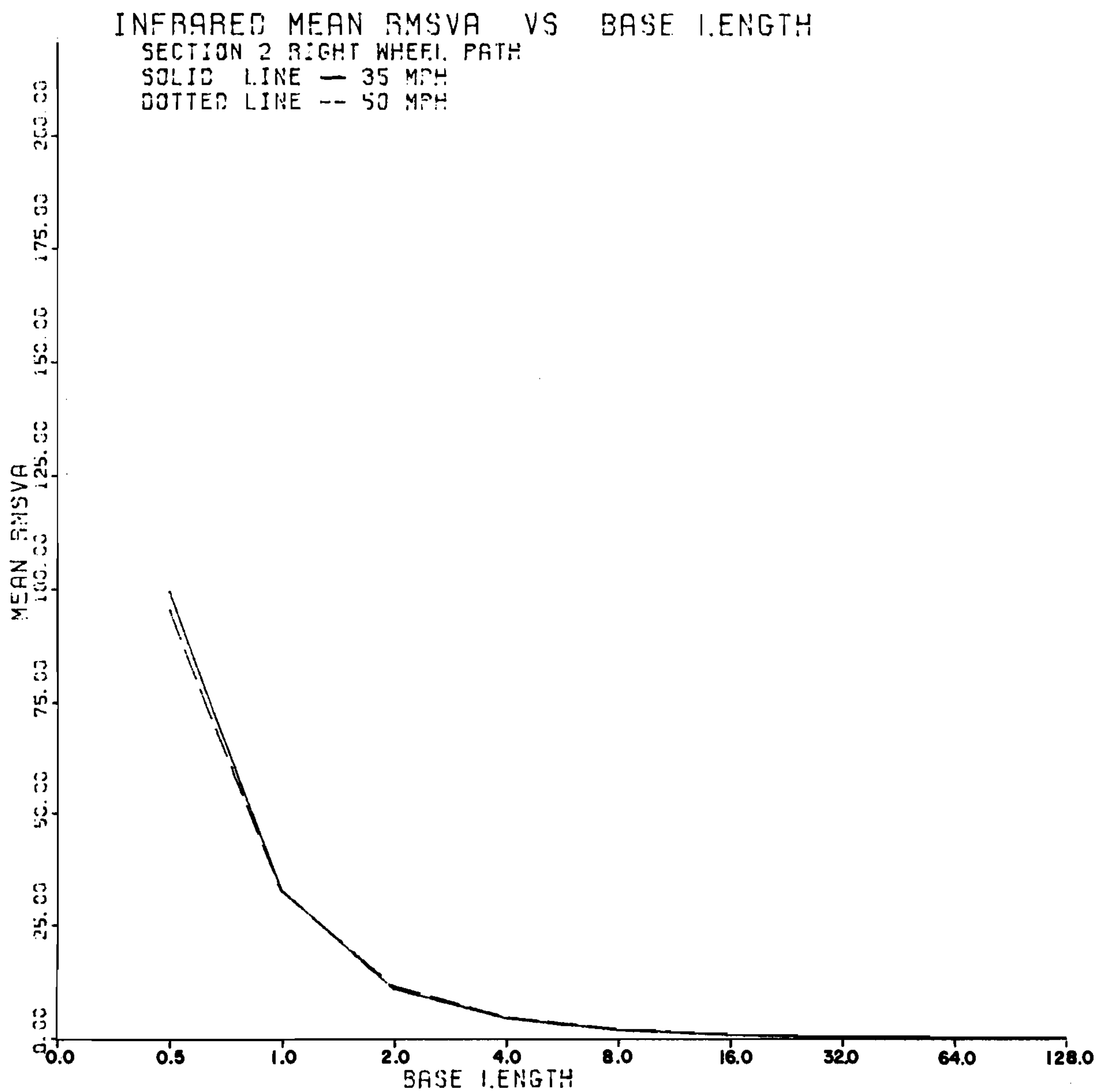

Profilometer with 300 wlf
CV vs Base Length on Sec 38 SI=1.0 y w/p
Solid Line — Left Wheel Path
Dotted Line -- Right Wheel Path
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
CV %
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

APPENDIX C

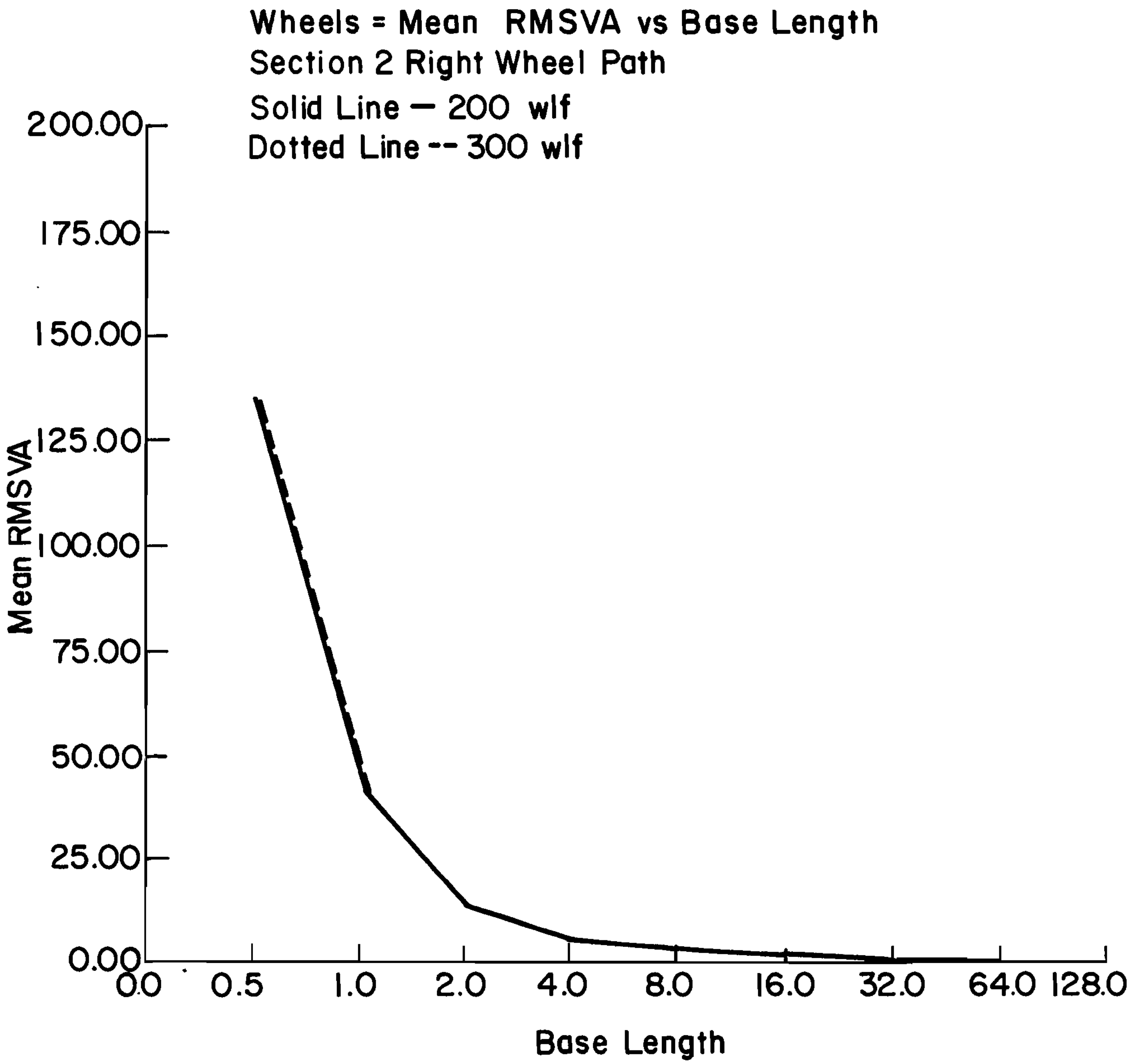
MEAN RMSVA FOR SECTIONS 2, 6, 5, 9, 7 AND 32

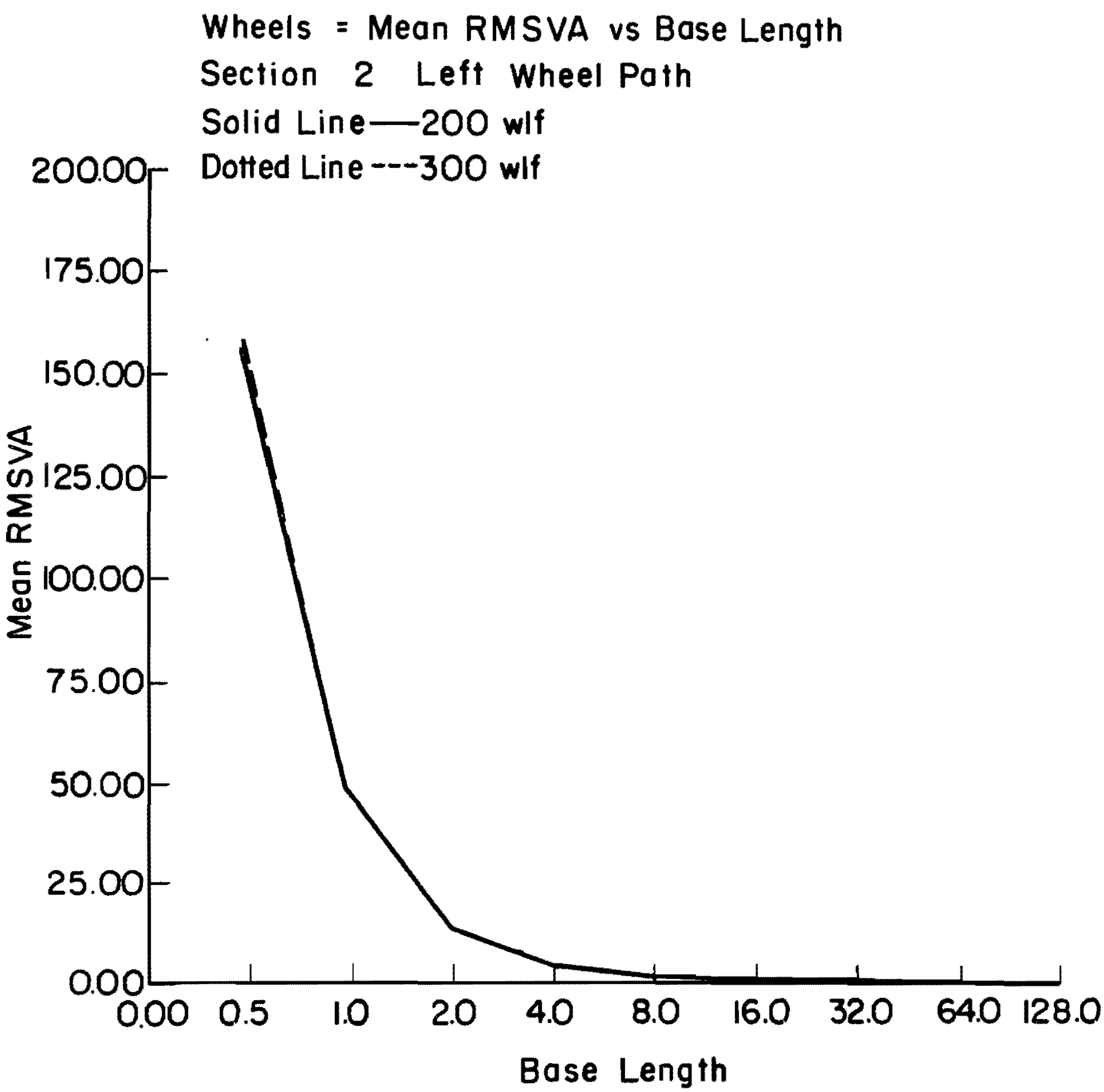

SELCOM -- MEAN RMSVA VS BASE LENGTH
SECTION 2 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

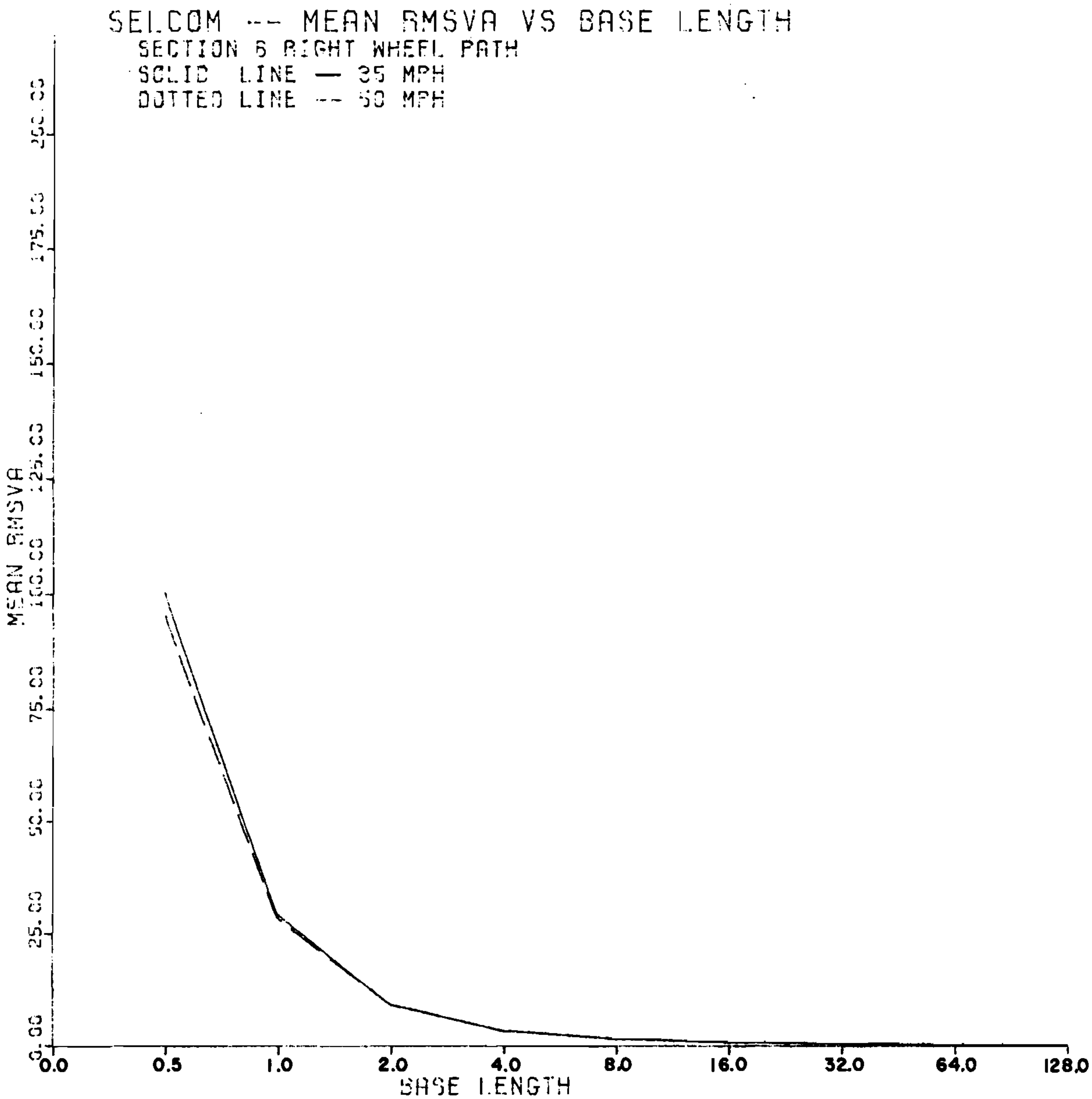
010 080


INFRARED MEAN RMSVA VS BASE LENGTH
SECTION 2 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

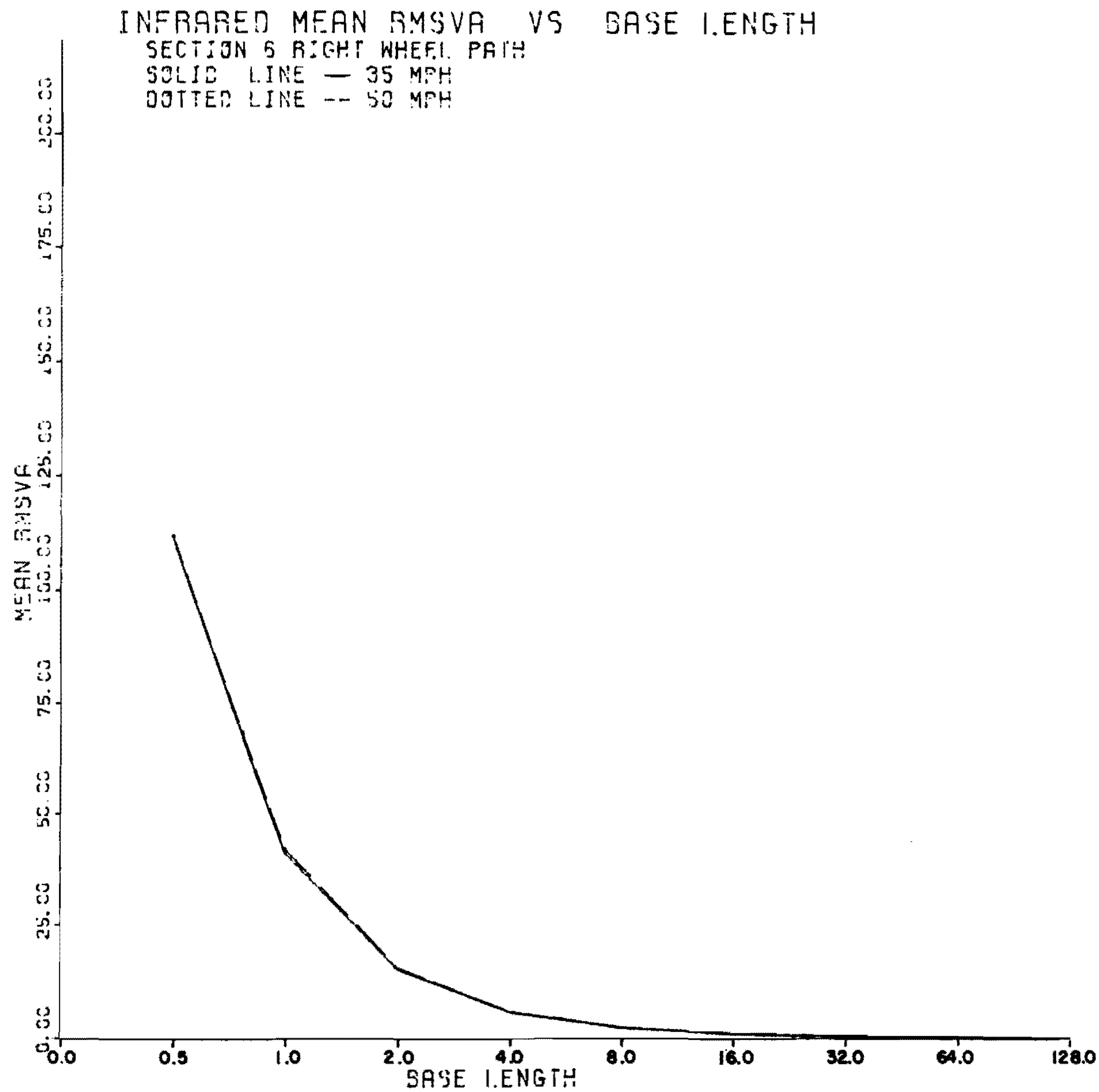
010 081

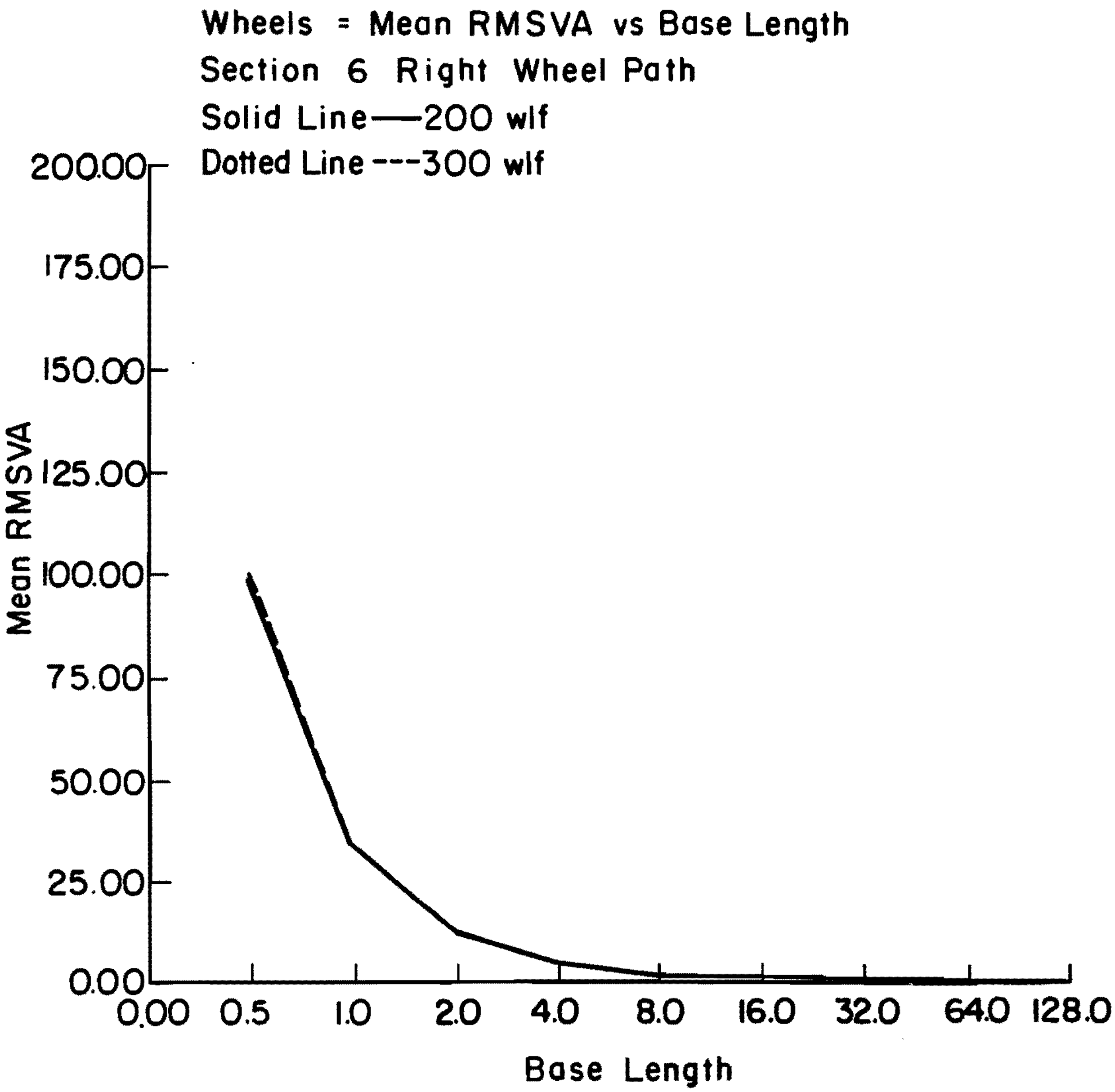

Wheels = Mean RMSVA vs Base Length
Section 2 Right Wheel Path
Solid Line — 200 wlf
Dotted Line -- 300 wlf
Mean RMSVA
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

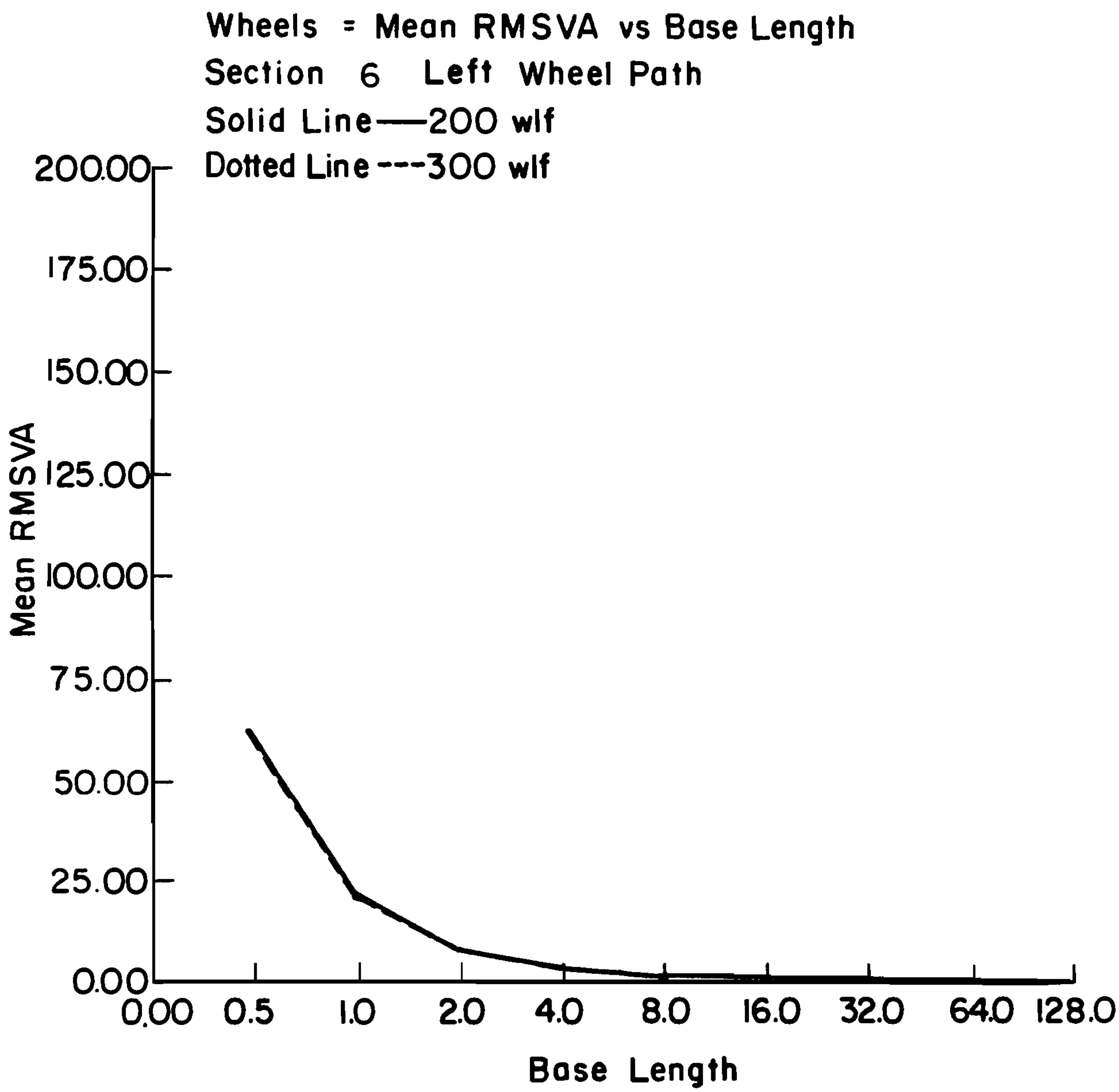

Wheels = Mean RMSVA vs Base Length
Section 2 Left Wheel Path
Solid Line—200 wlf
Dotted Line ---300 wlf
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

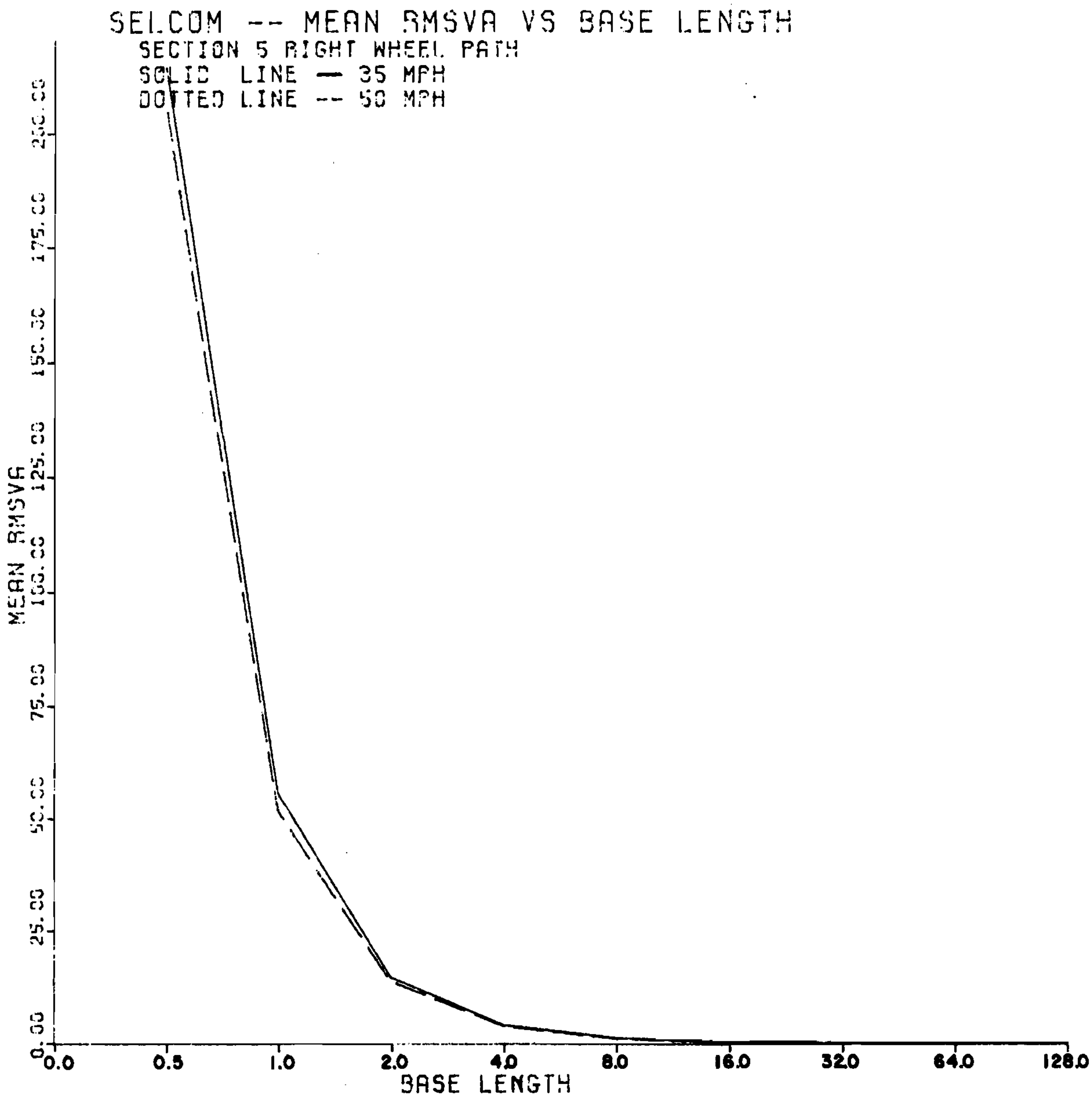

SELCOM -- MEAN RMSVA VS BASE LENGTH
SECTION 6 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

010 078

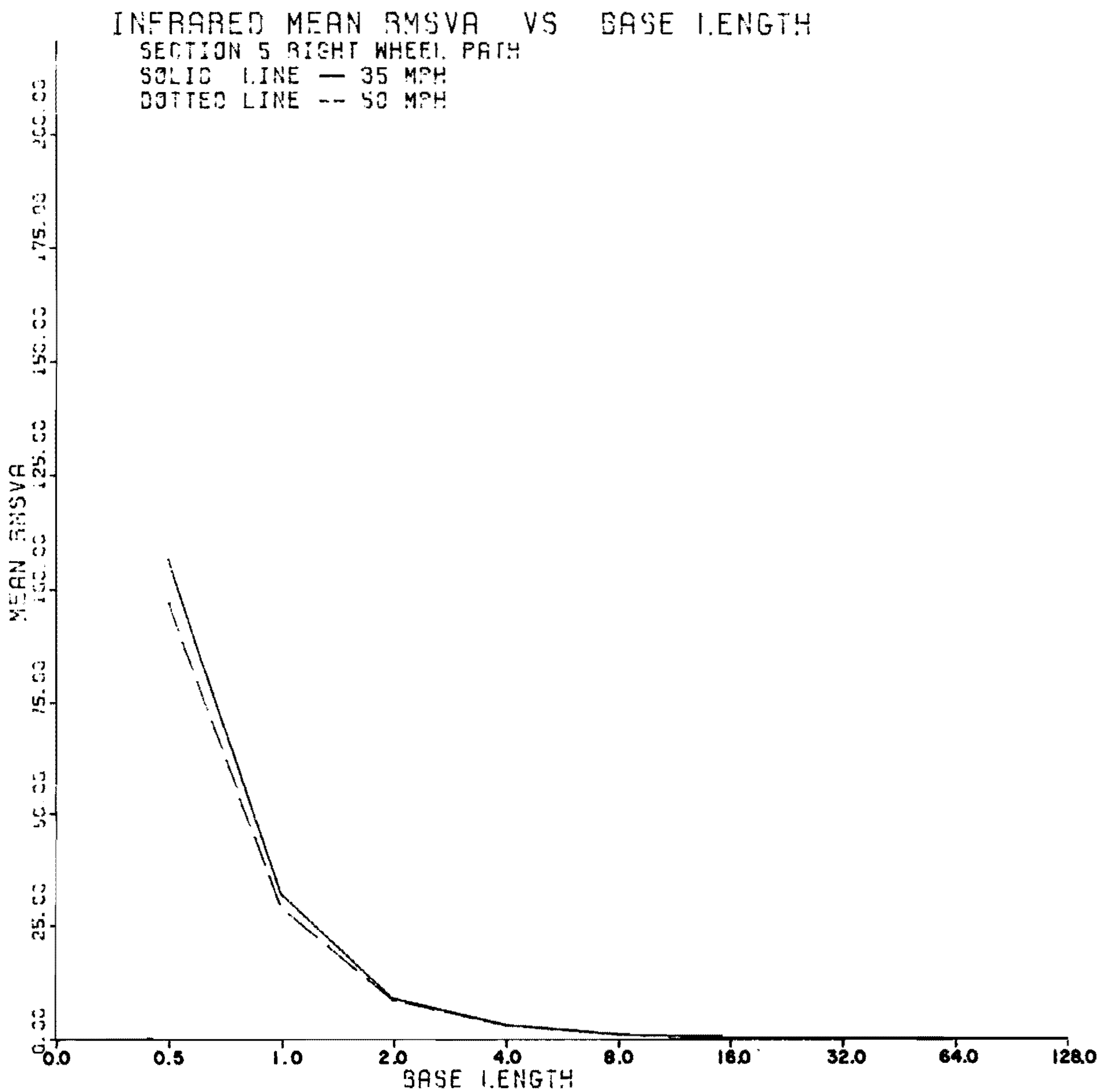

INFRARED MEAN RMSVA VS BASE LENGTH
SECTION 6 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

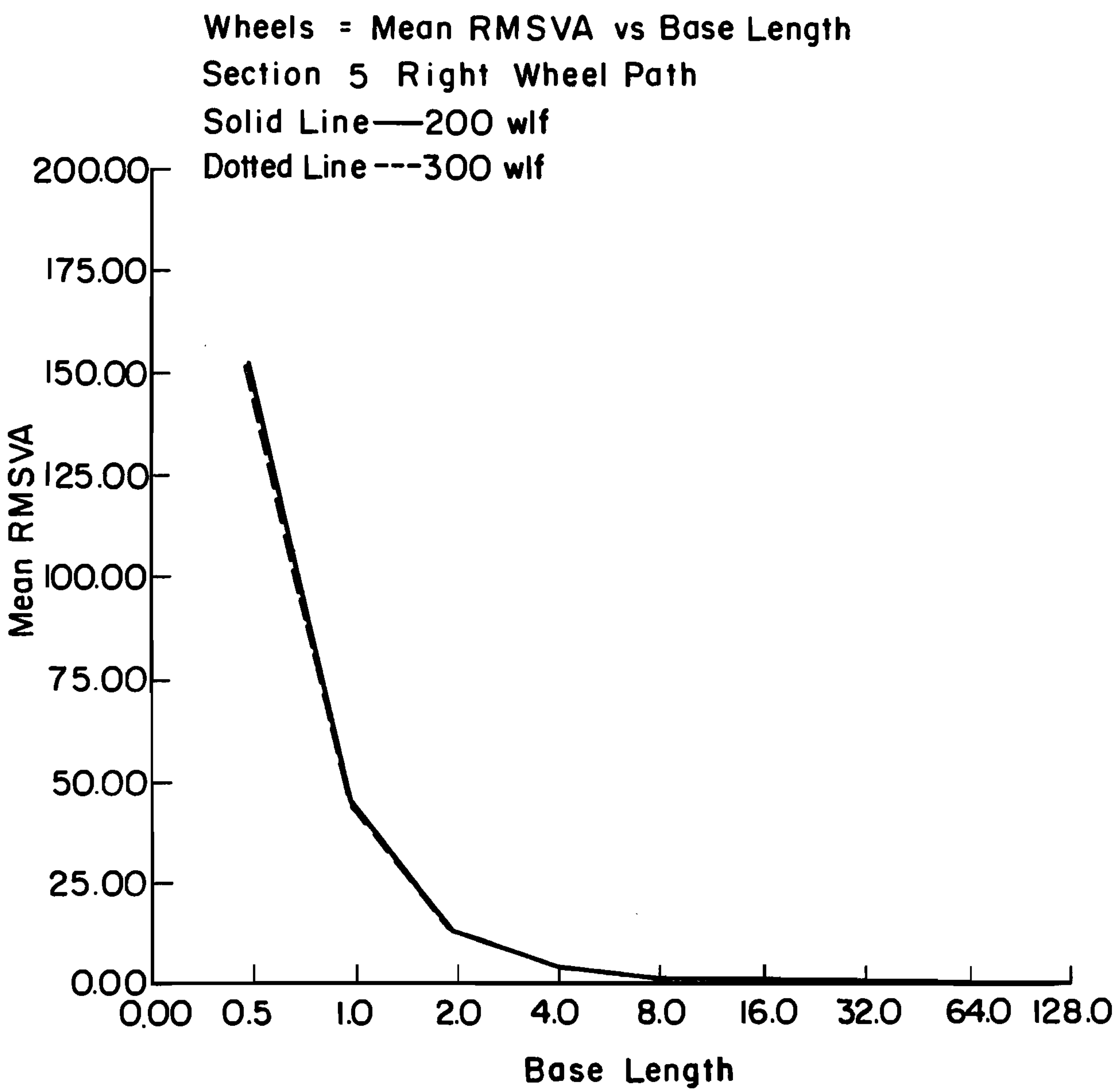

Wheels = Mean RMSVA vs Base Length
Section 6 Right Wheel Path
Solid Line——200 wlf
Dotted Line ---300 wlf
Mean RMSVA
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

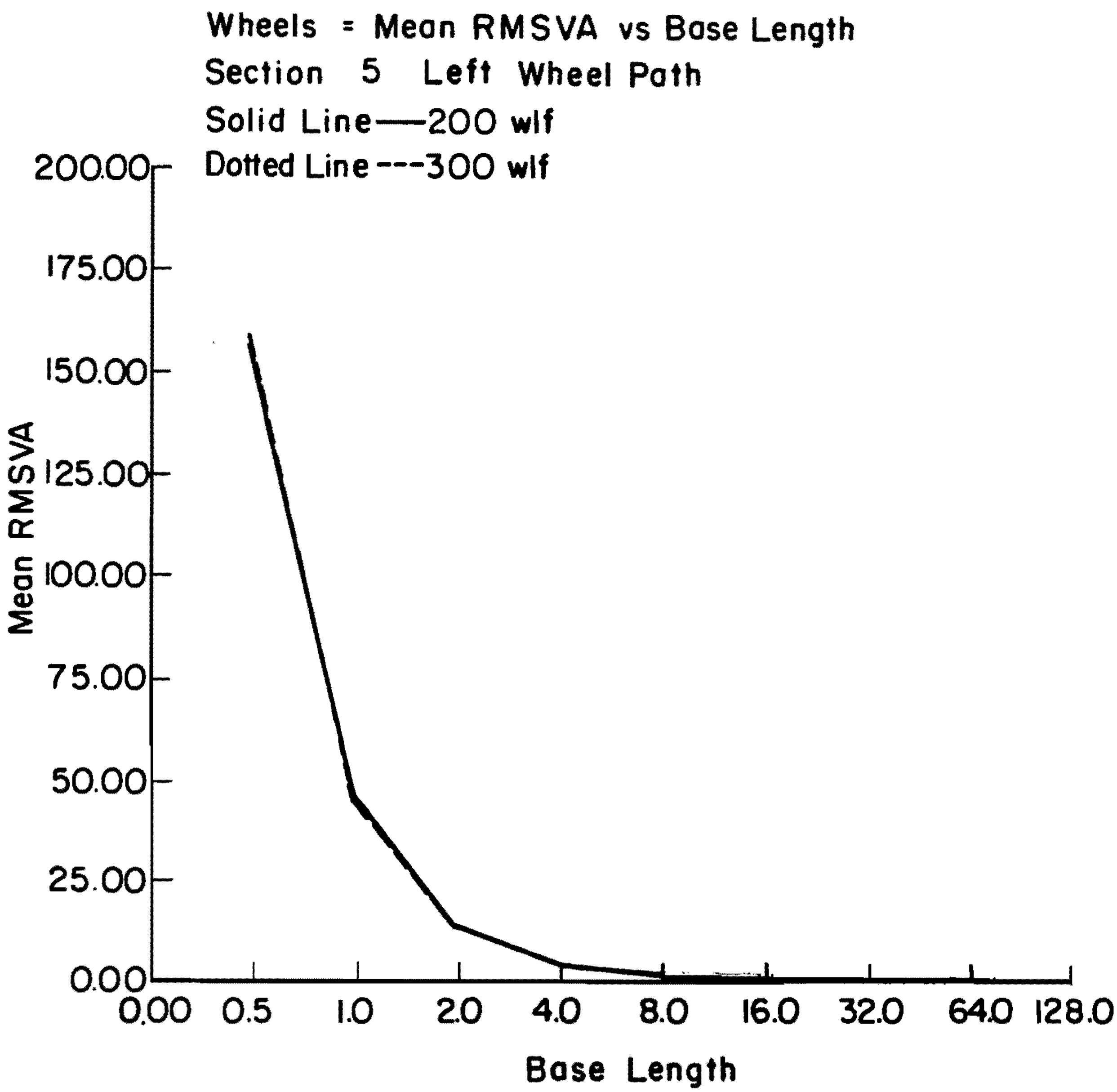

Wheels = Mean RMSVA vs Base Length
Section 6 Left Wheel Path
Solid Line——200 wlf
Dotted Line---300 wlf
Mean RMSVA
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

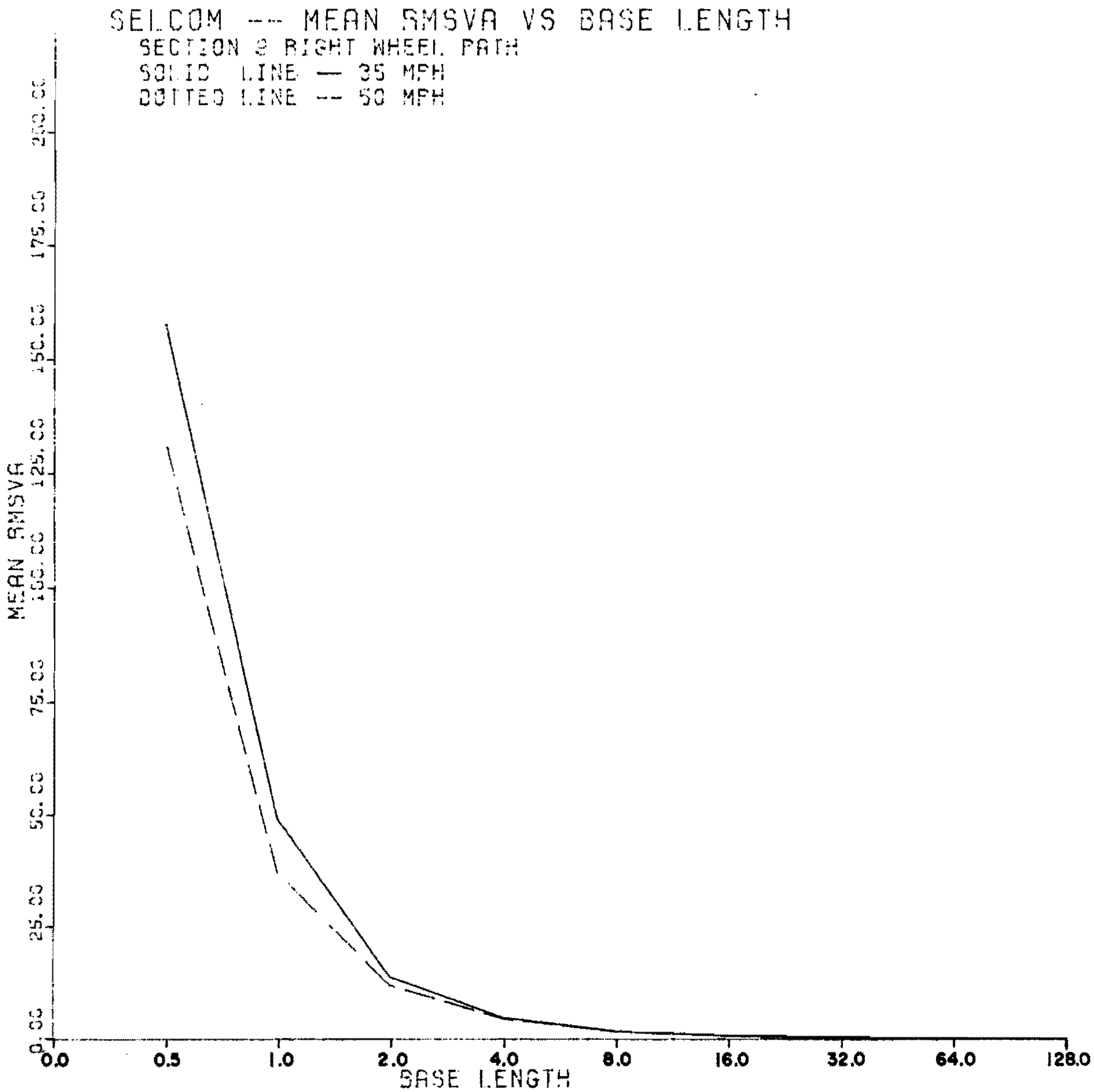

SELCOM -- MEAN RMSVA VS BASE LENGTH
SECTION 5 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

010 082

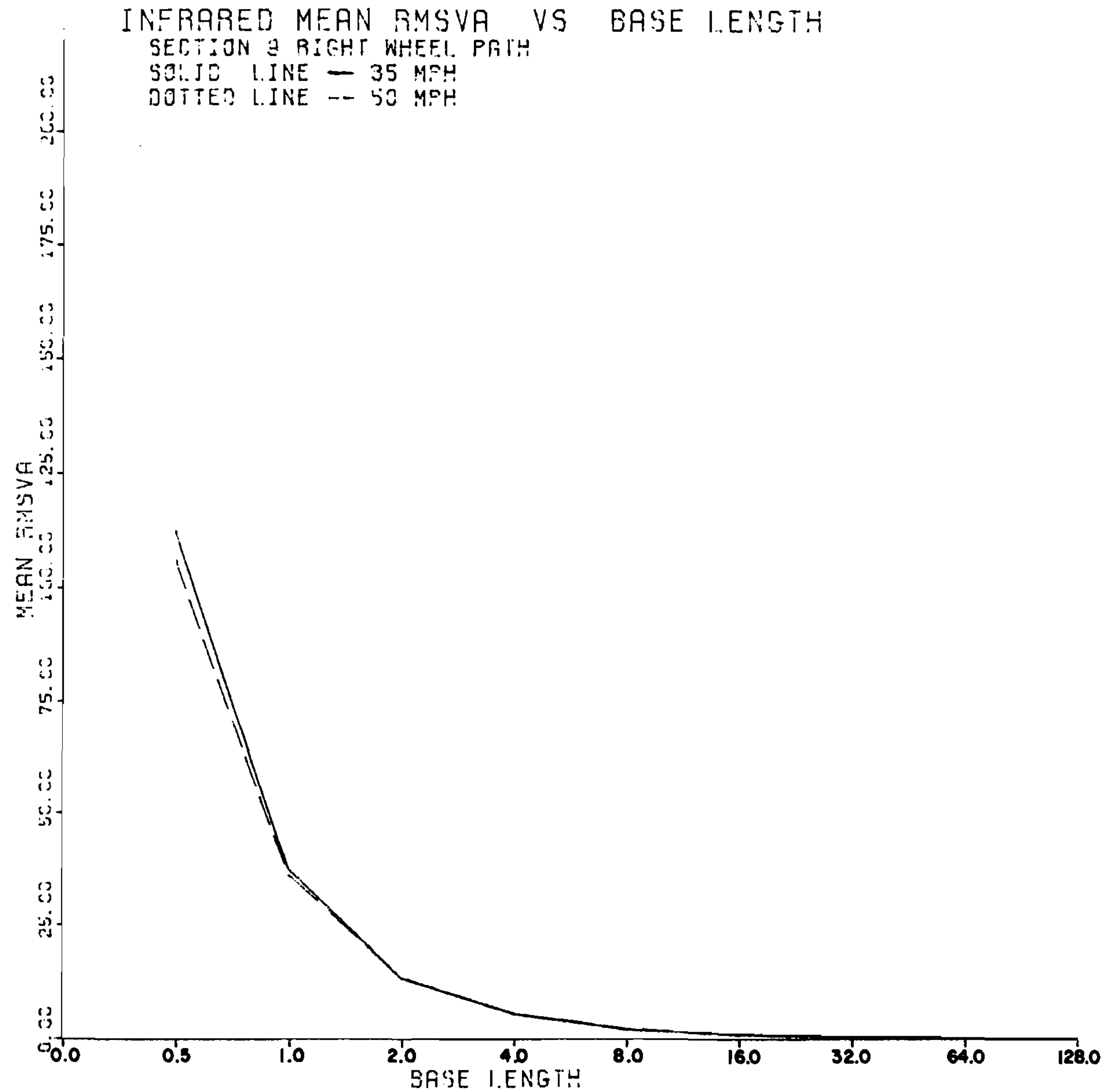

INFRARED MEAN RMSVA VS BASE LENGTH
SECTION 5 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
BASE LENGTH
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00

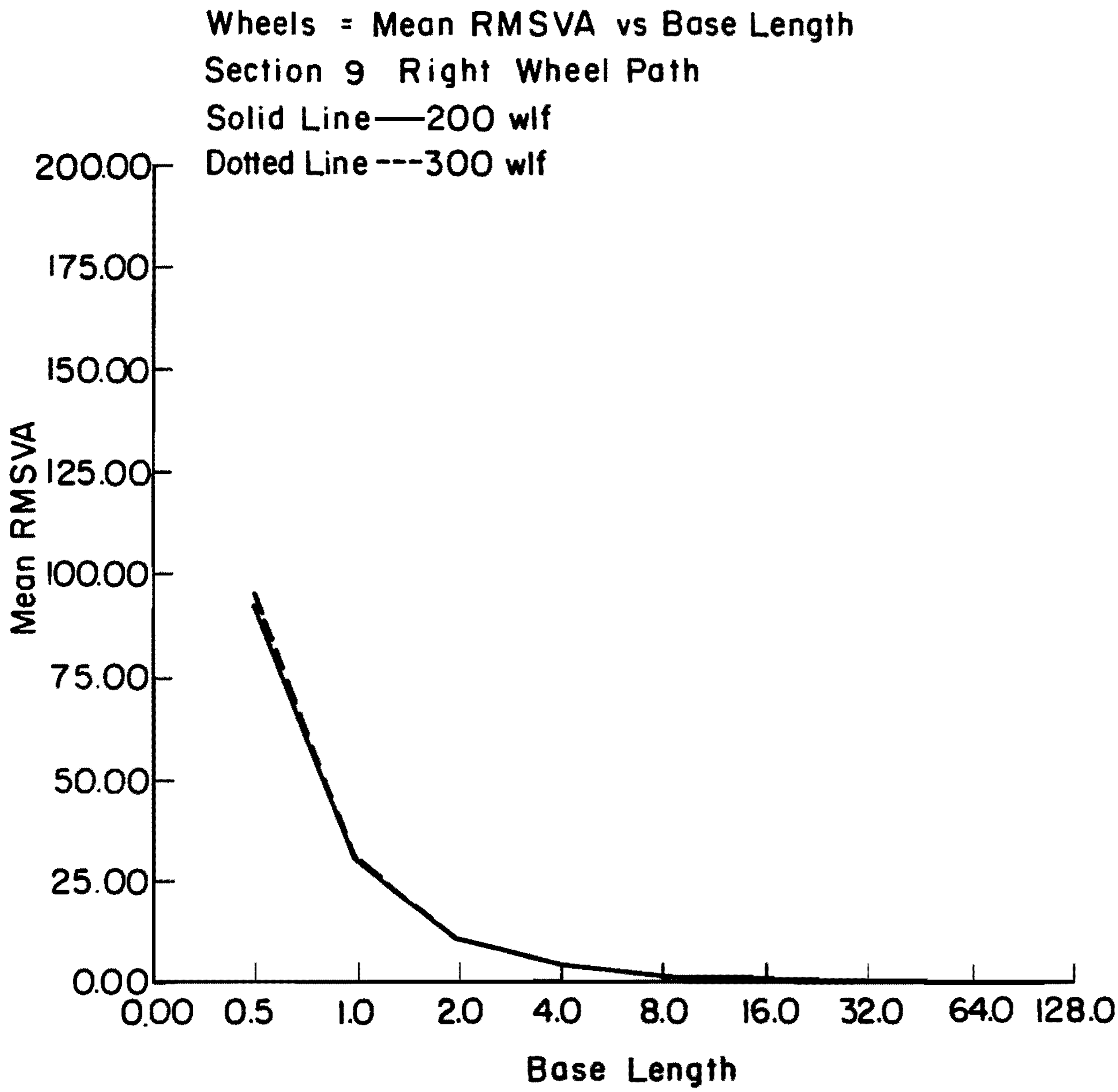

Wheels = Mean RMSVA vs Base Length
Section 5 Right Wheel Path
Solid Line——200 wlf
Dotted Line---300 wlf
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length


Wheels = Mean RMSVA vs Base Length
Section 5 Left Wheel Path
Solid Line—200 wlf
Dotted Line---300 wlf
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

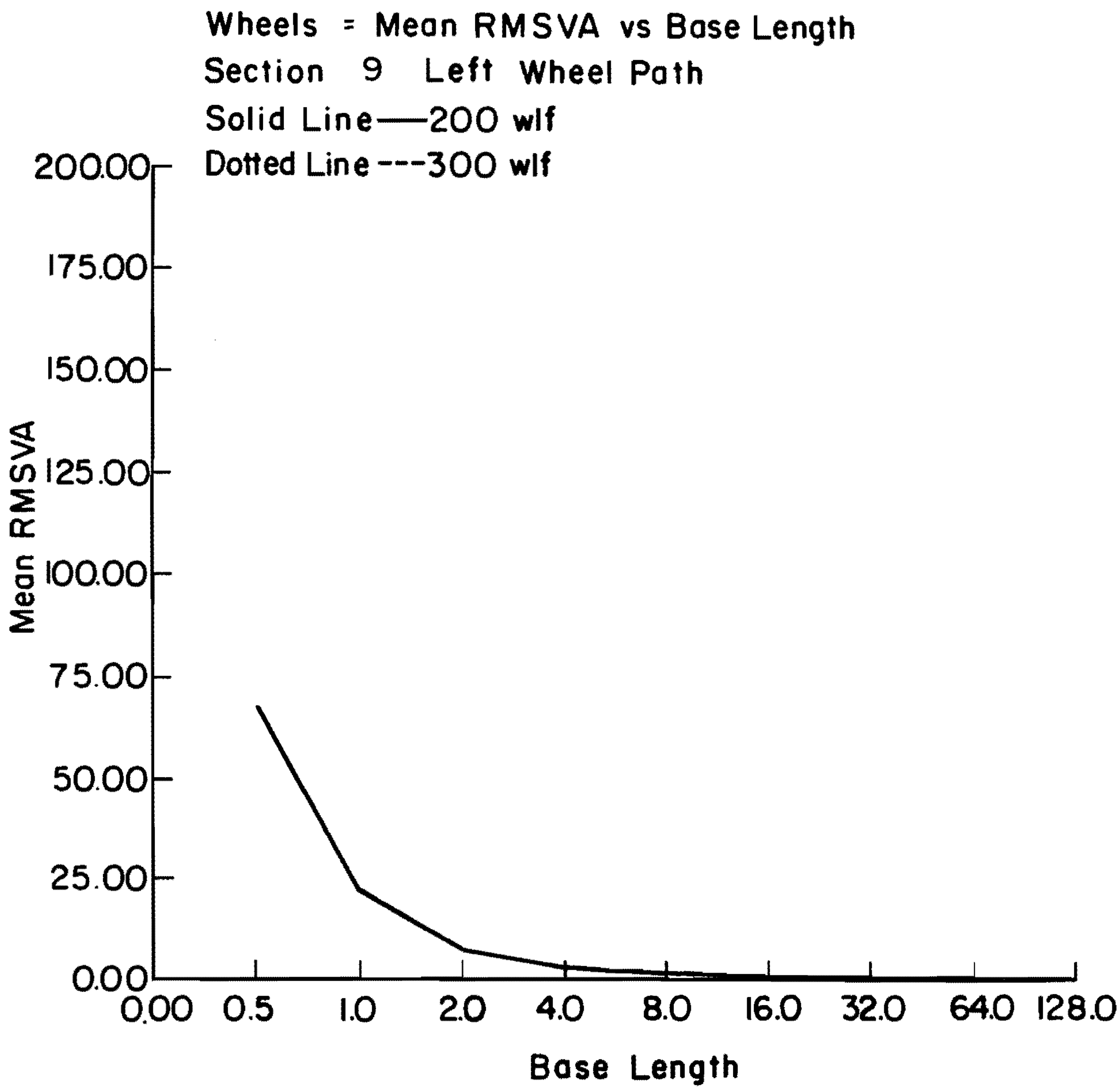

SELCOM -- MEAN RMSVA VS BASE LENGTH
SECTION 8 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

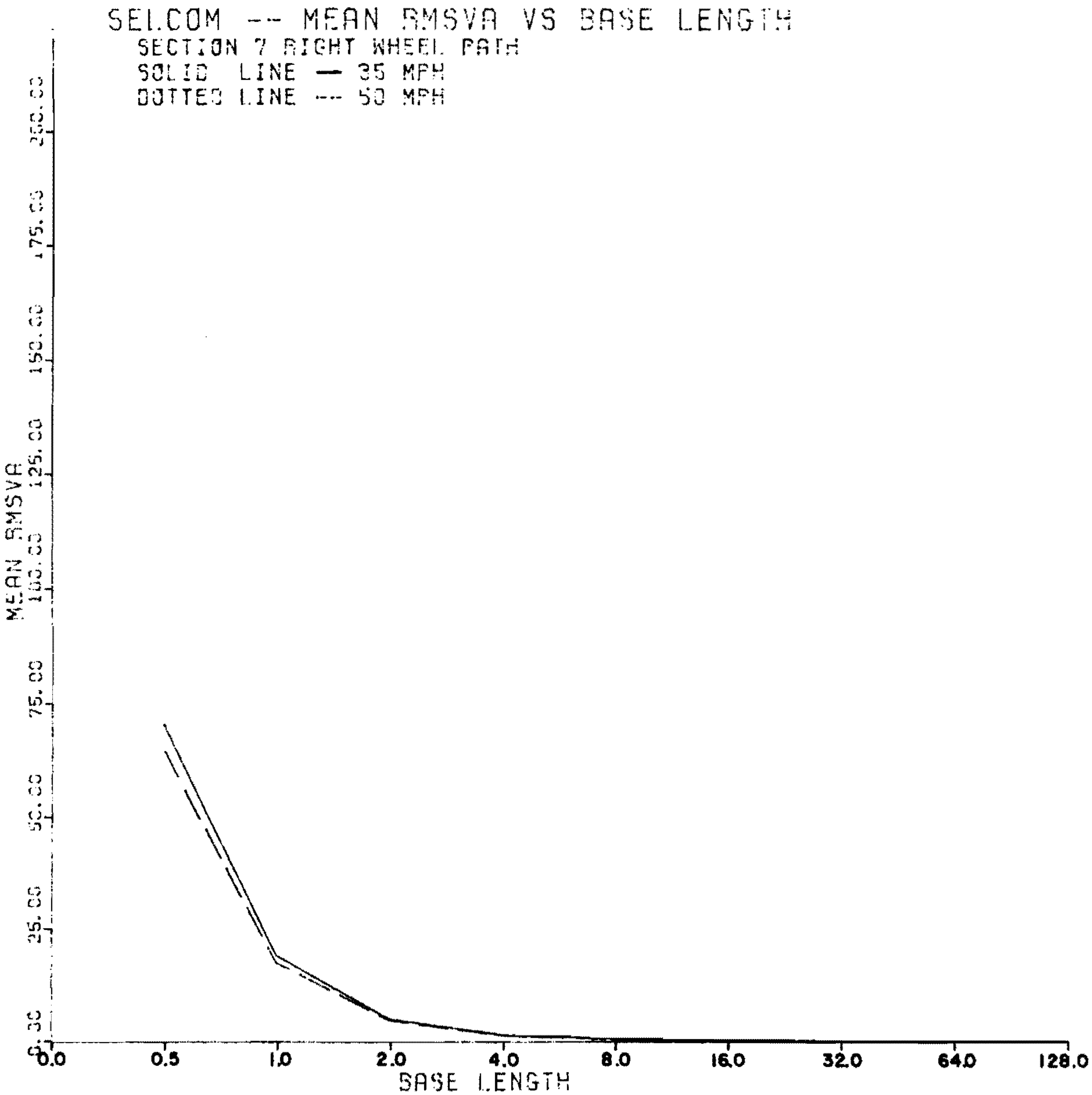
010 084

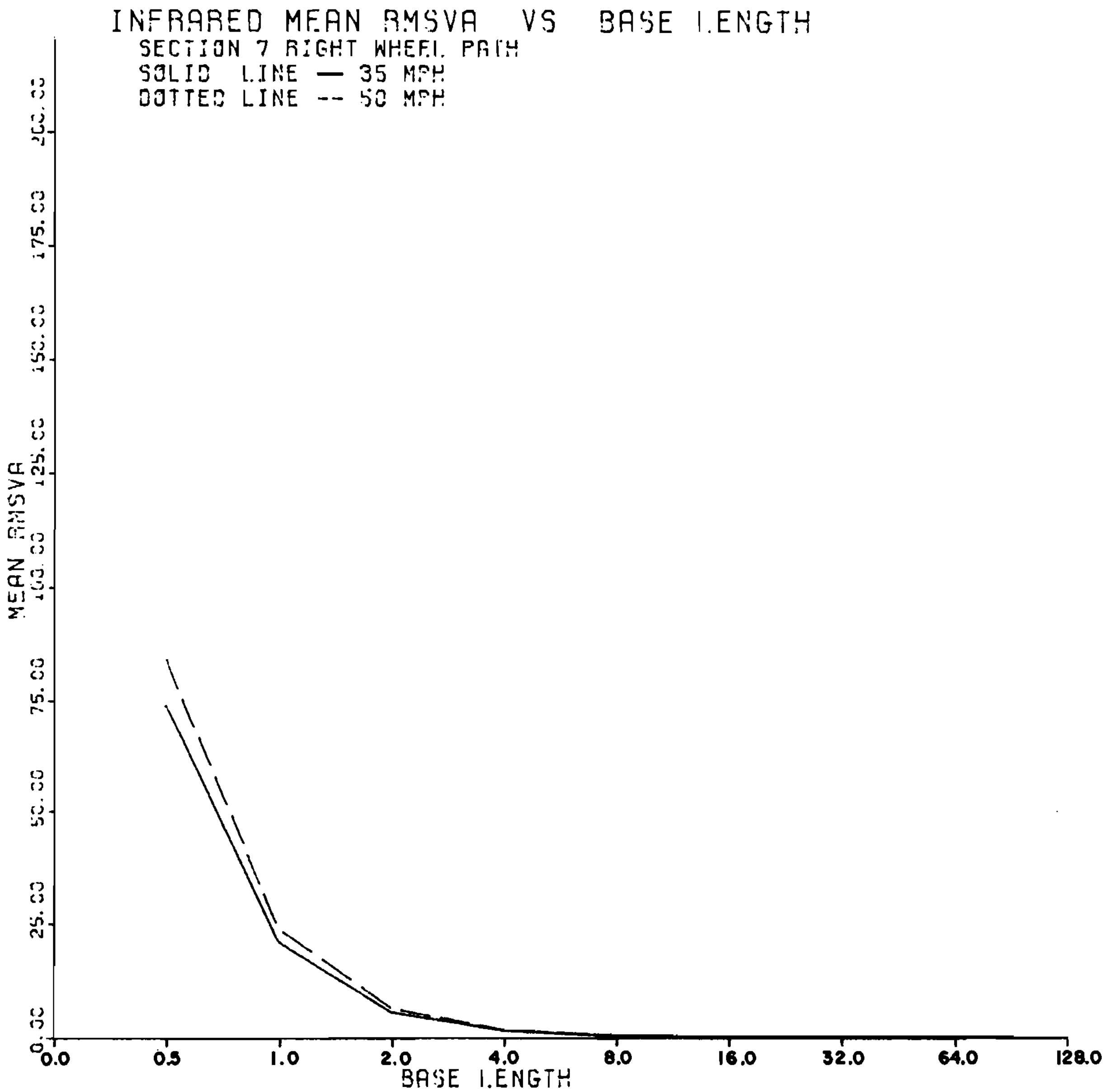

INFRARED MEAN RMSVA VS BASE LENGTH
SECTION 9 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

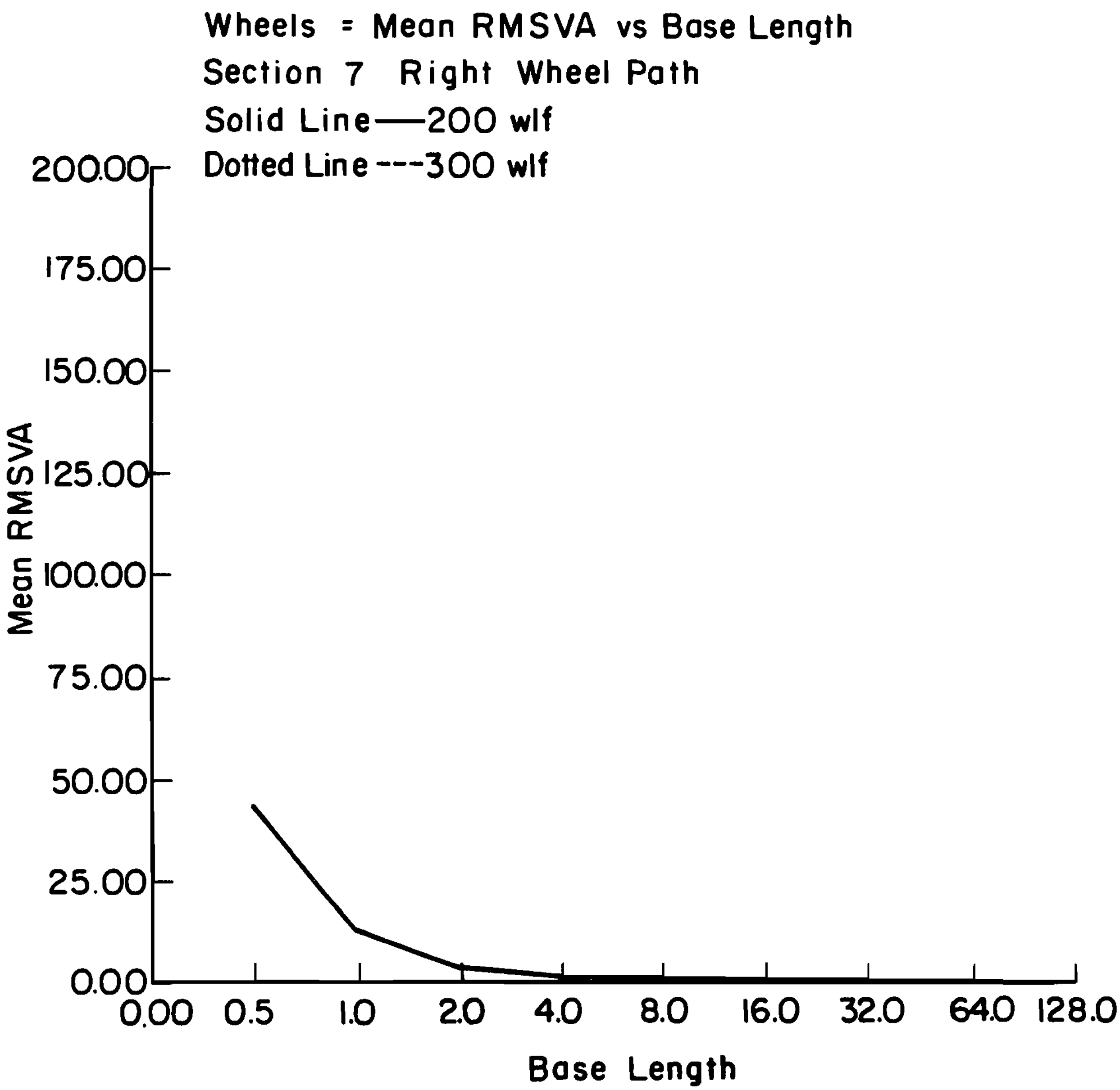

Wheels = Mean RMSVA vs Base Length
Section 9 Right Wheel Path
Solid Line——200 wlf
Dotted Line---300 wlf
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

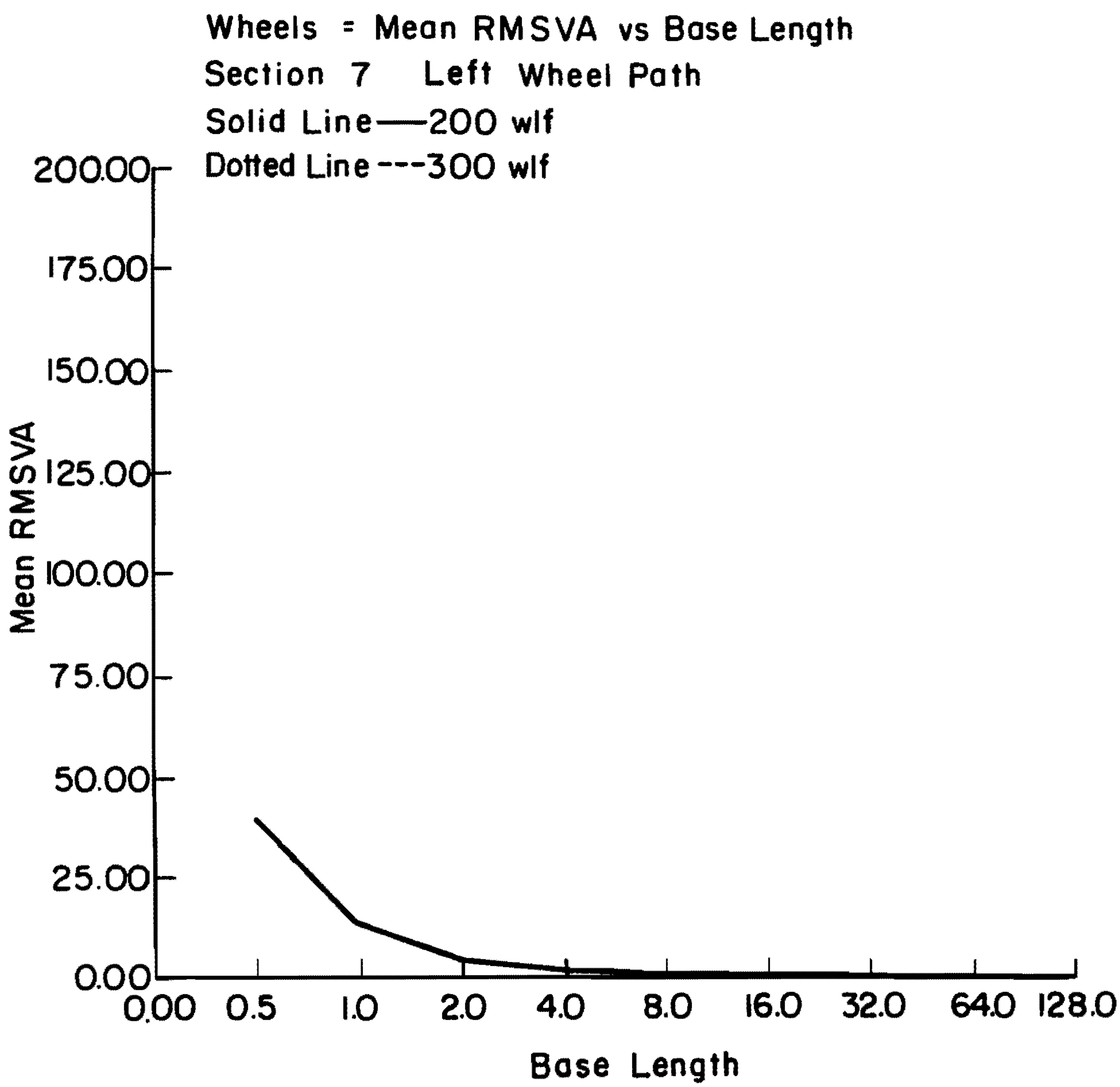
010 095

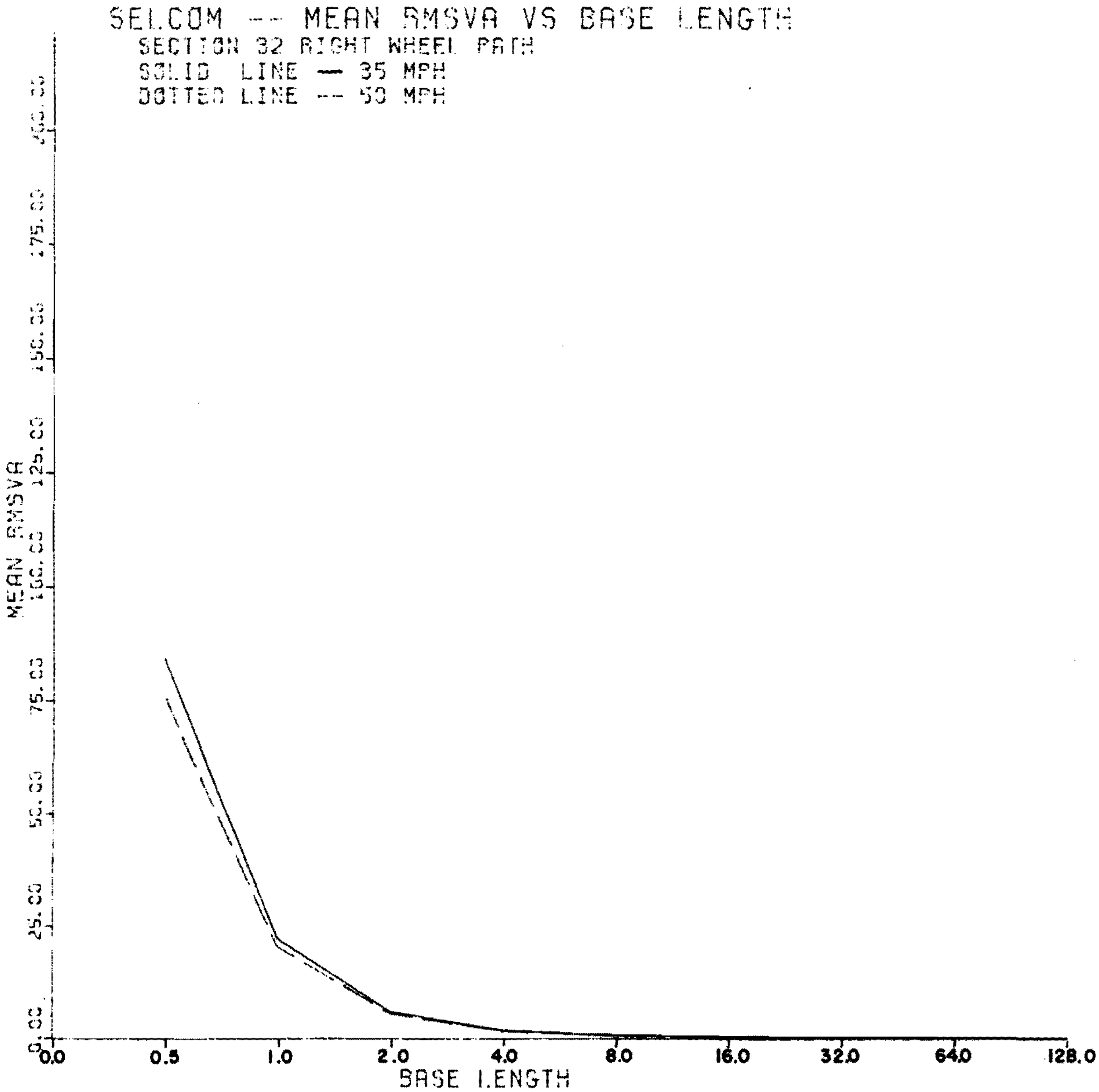

Wheels = Mean RMSVA vs Base Length
Section 9 Left Wheel Path
Solid Line—200 wlf
Dotted Line---300 wlf
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

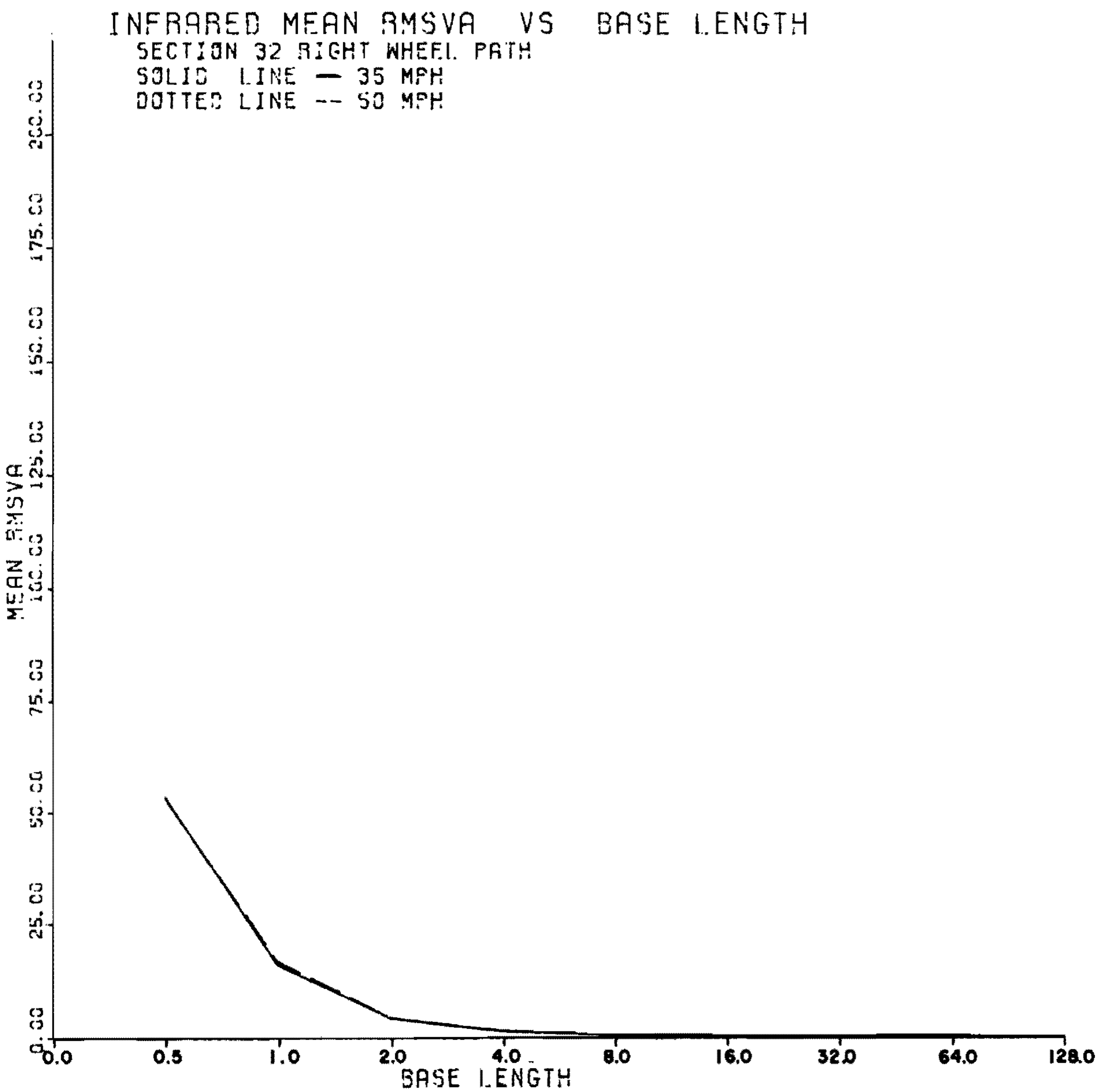

SELCOM -- MEAN RMSVA VS BASE LENGTH
SECTION 7 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH


INFRARED MEAN RMSVA VS BASE LENGTH
SECTION 7 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
BASE LENGTH
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0

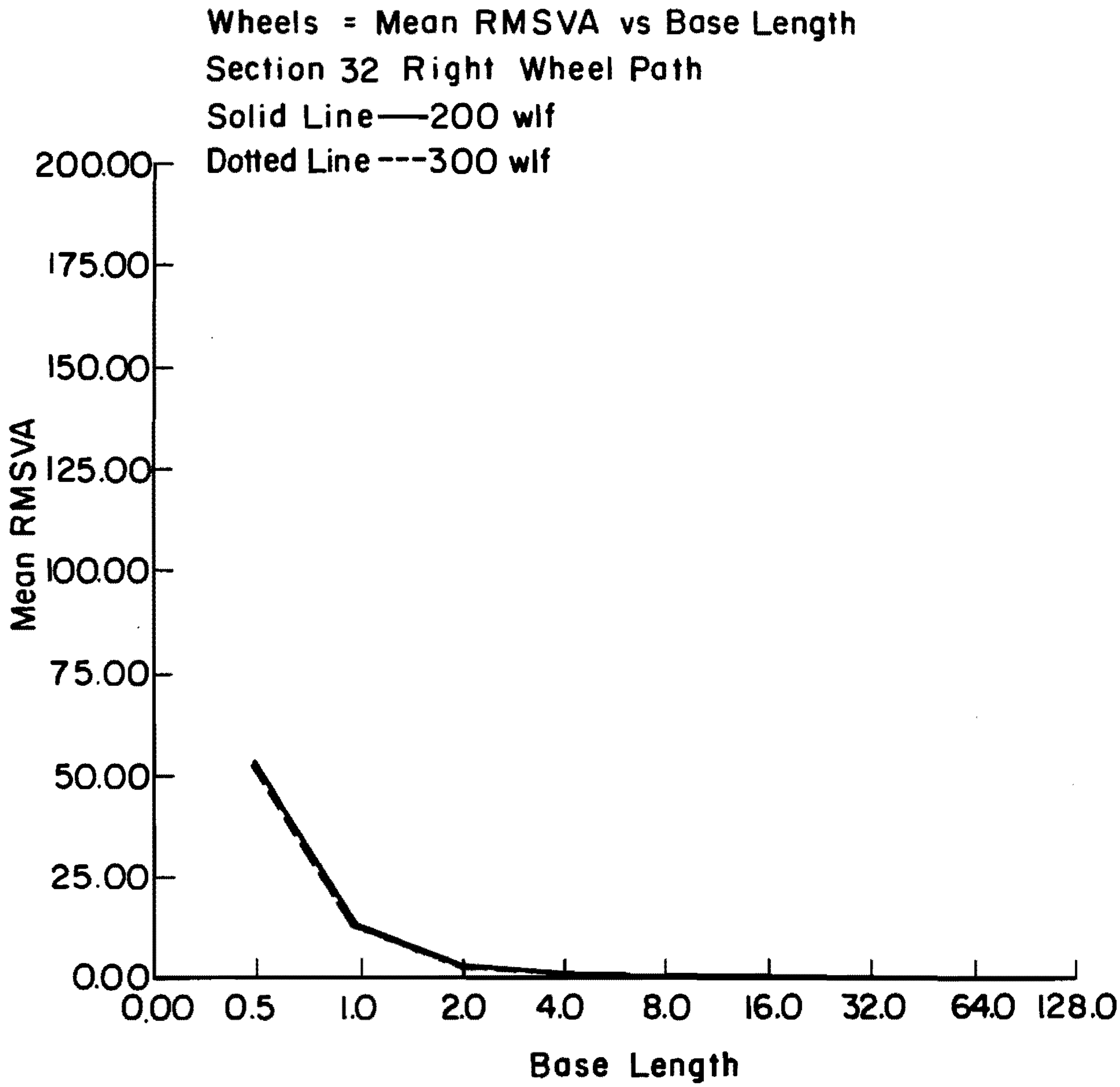

Wheels = Mean RMSVA vs Base Length
Section 7 Right Wheel Path
Solid Line——200 wlf
Dotted Line---300 wlf
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

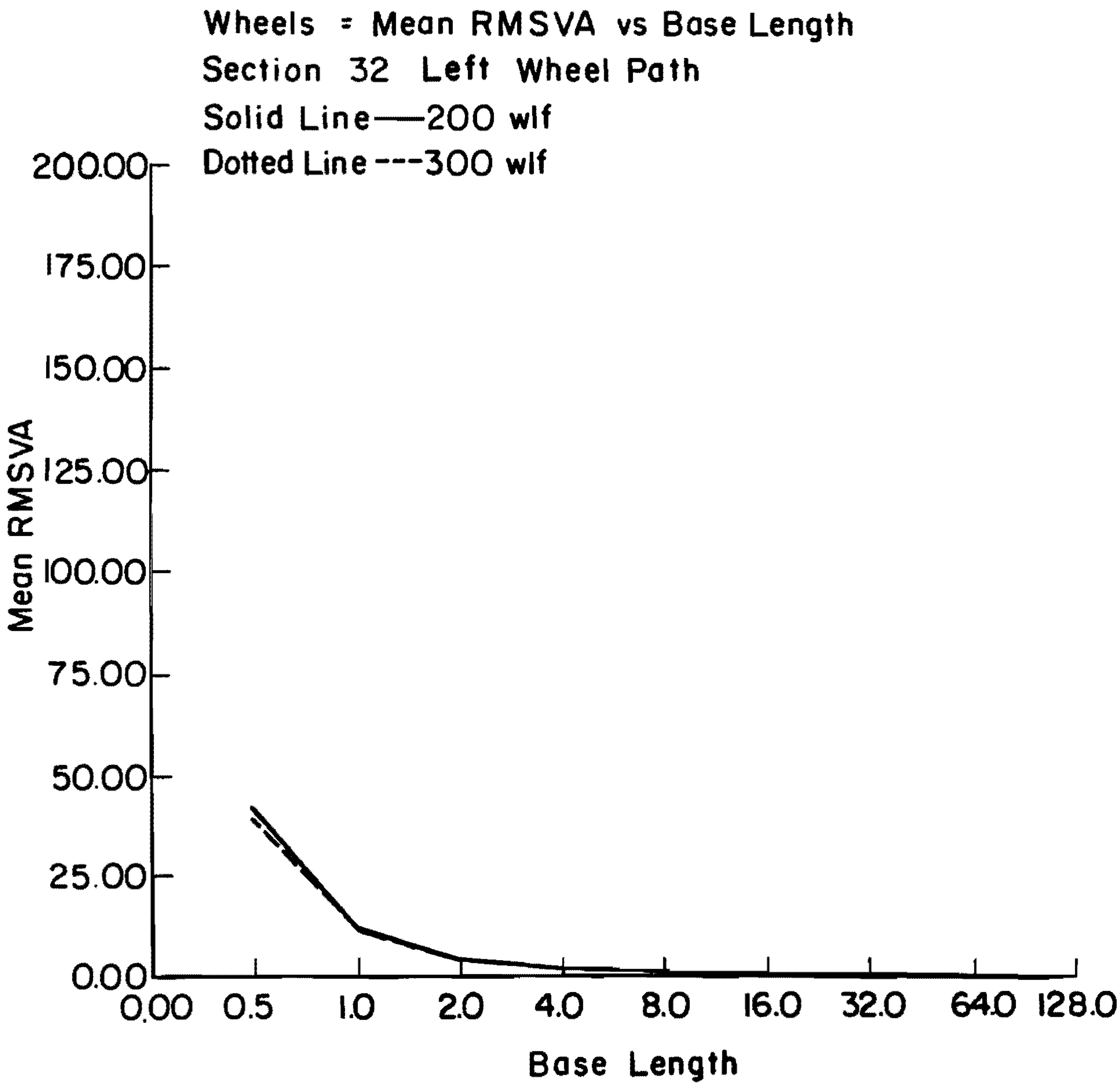

Wheels = Mean RMSVA vs Base Length
Section 7 Left Wheel Path
Solid Line—200 wlf
Dotted Line---300 wlf
Mean RMSVA
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0.00 0.5 1.0 2.0 4.0 8.0 16.0 32.0 64.0 128.0
Base Length

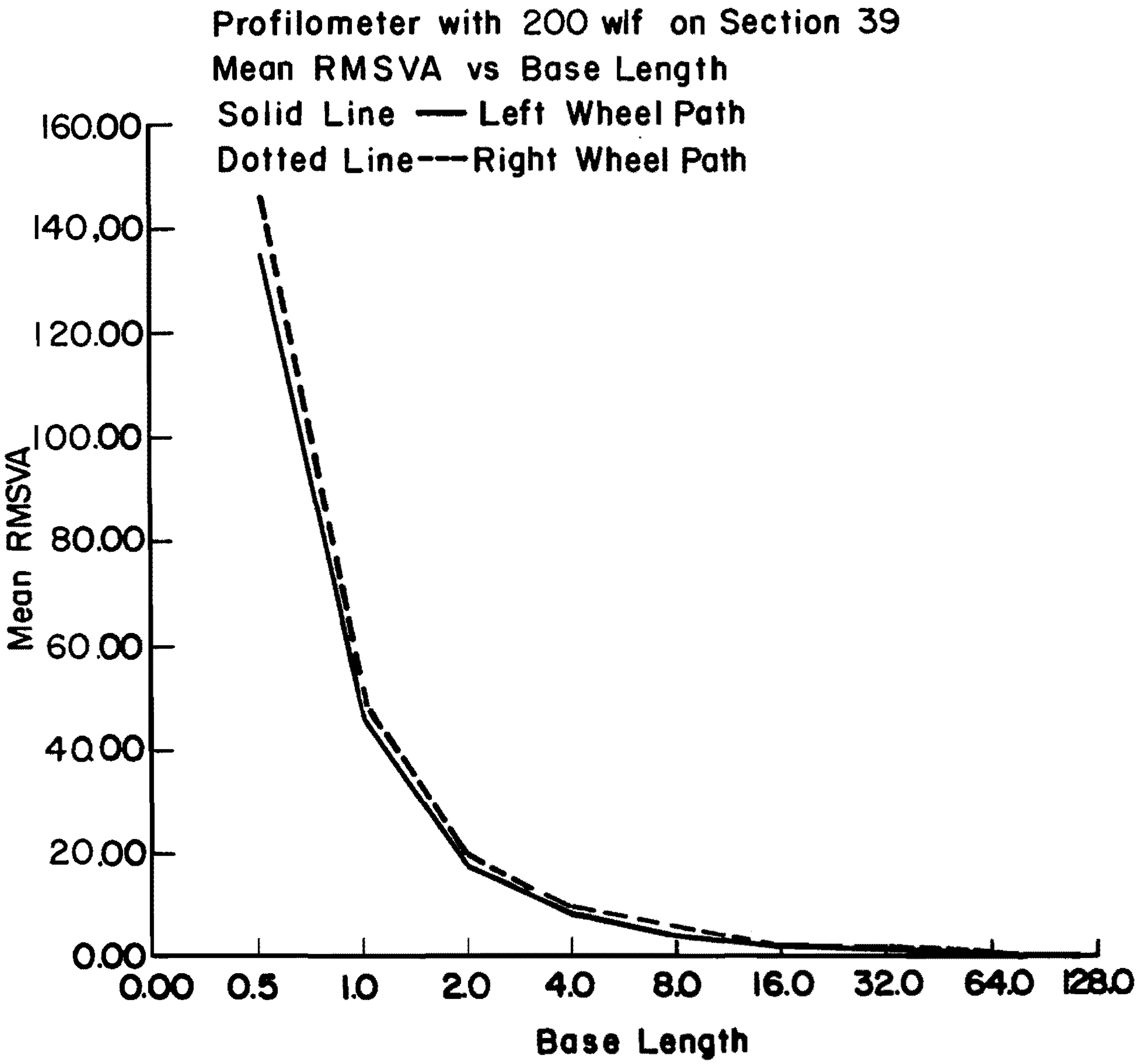

SELCOM -- MEAN RMSVA VS BASE LENGTH
SECTION 32 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

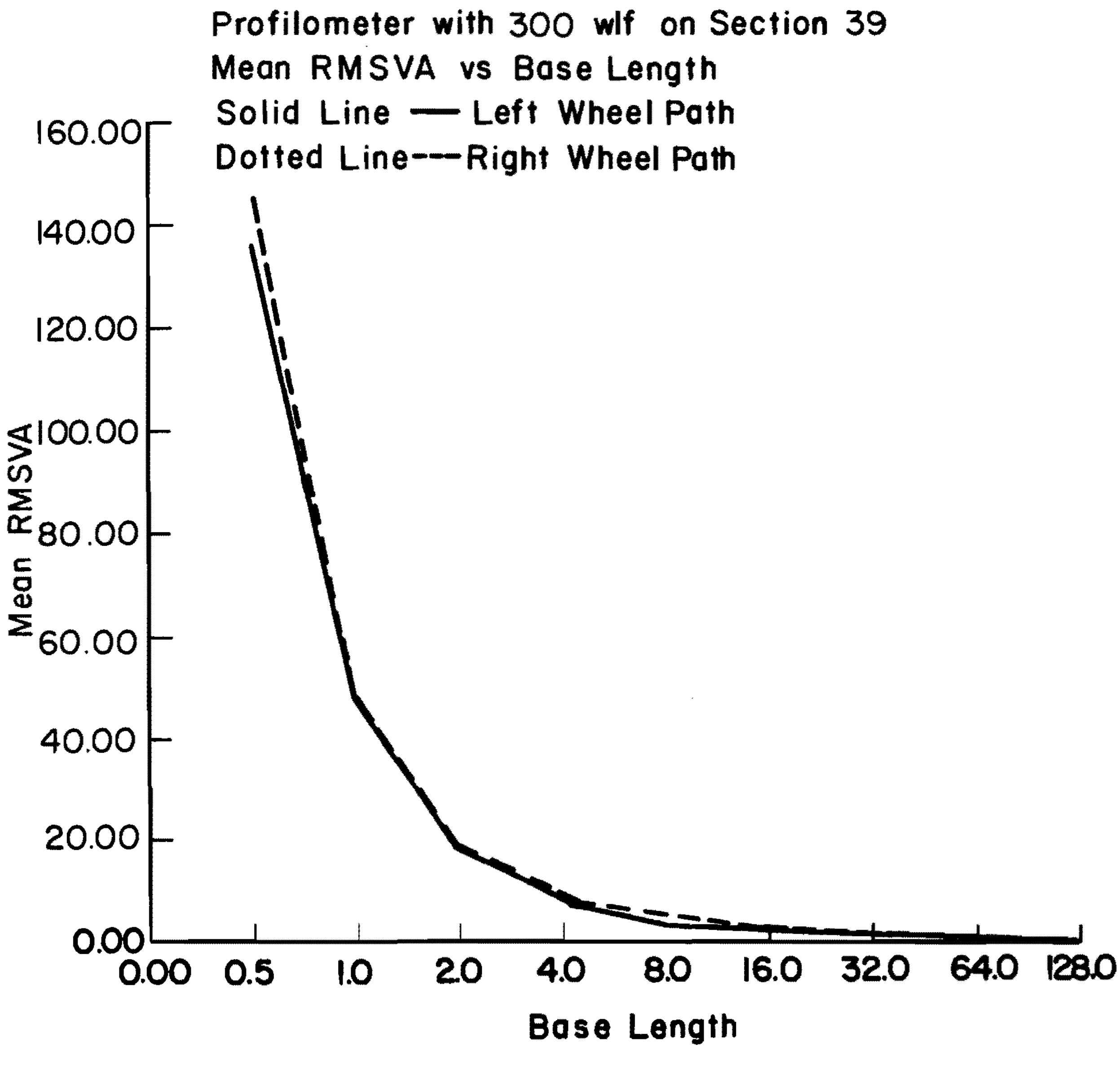

INFRARED MEAN RMSVA VS BASE LENGTH
SECTION 32 RIGHT WHEEL PATH
SOLID LINE — 35 MPH
DOTTED LINE -- 50 MPH
MEAN RMSVA
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

010 089


Wheels = Mean RMSVA vs Base Length
Section 32 Right Wheel Path
Solid Line——200 wlf
Dotted Line---300 wlf
Mean RMSVA
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length


Wheels = Mean RMSVA vs Base Length
Section 32 Left Wheel Path
Solid Line—200 wlf
Dotted Line---300 wlf
Mean RMSVA
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

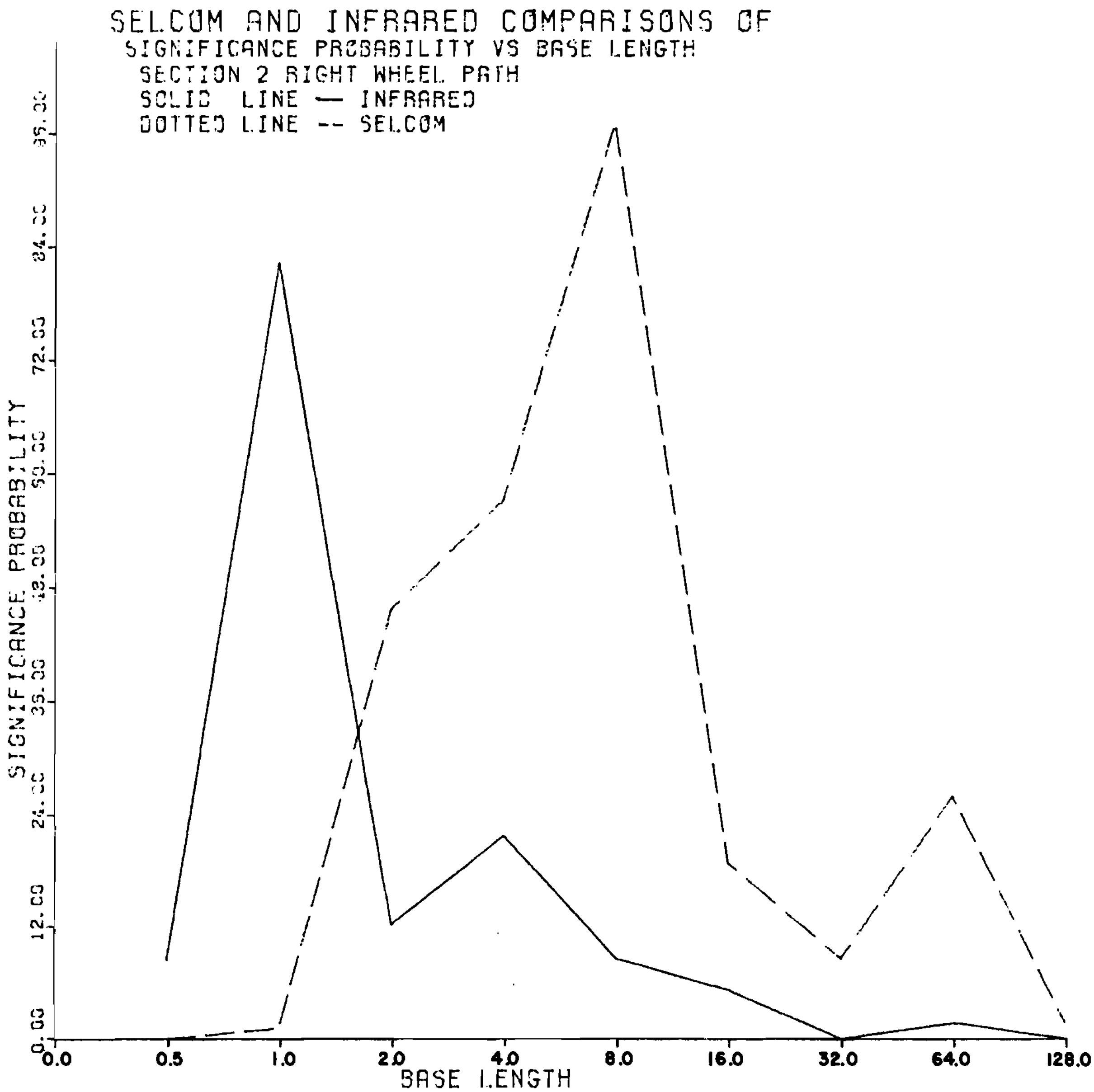

Profilometer with 200 wlf on Section 39
Mean RMSVA vs Base Length
Solid Line — Left Wheel Path
Dotted Line--- Right Wheel Path
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

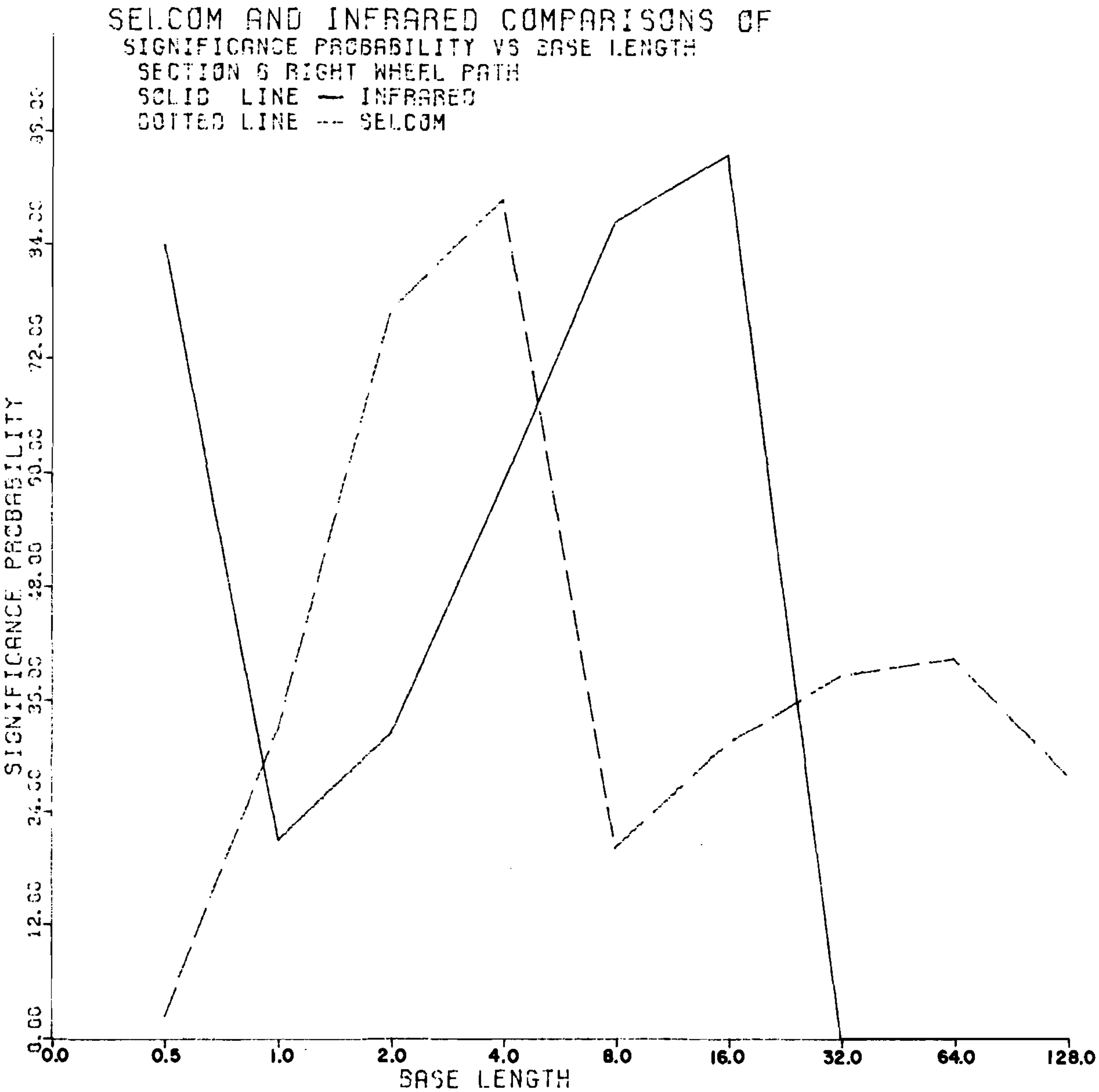


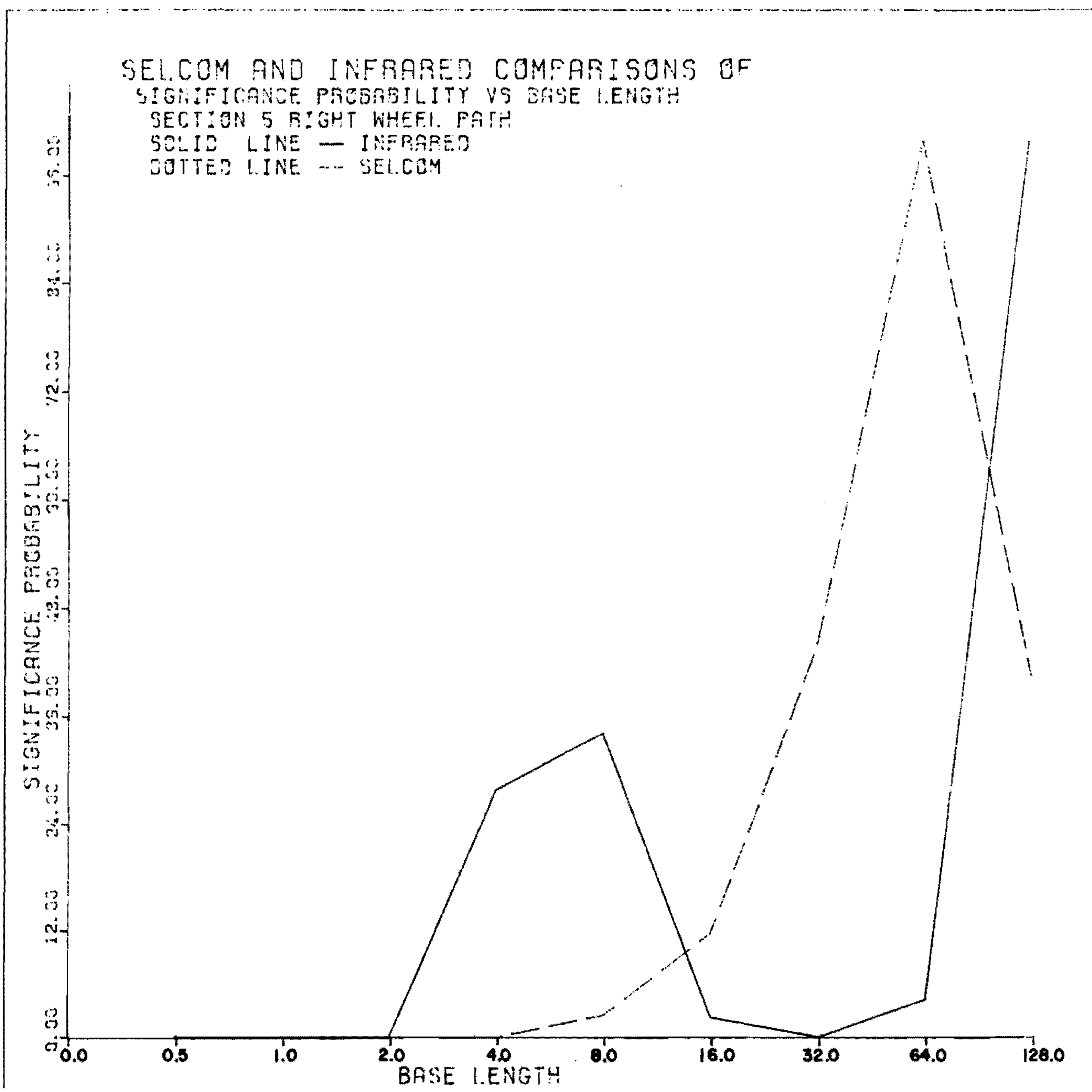
Profilometer with 300 wlf on Section 39
Mean RMSVA vs Base Length
Solid Line —— Left Wheel Path
Dotted Line---Right Wheel Path
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Mean RMSVA
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length

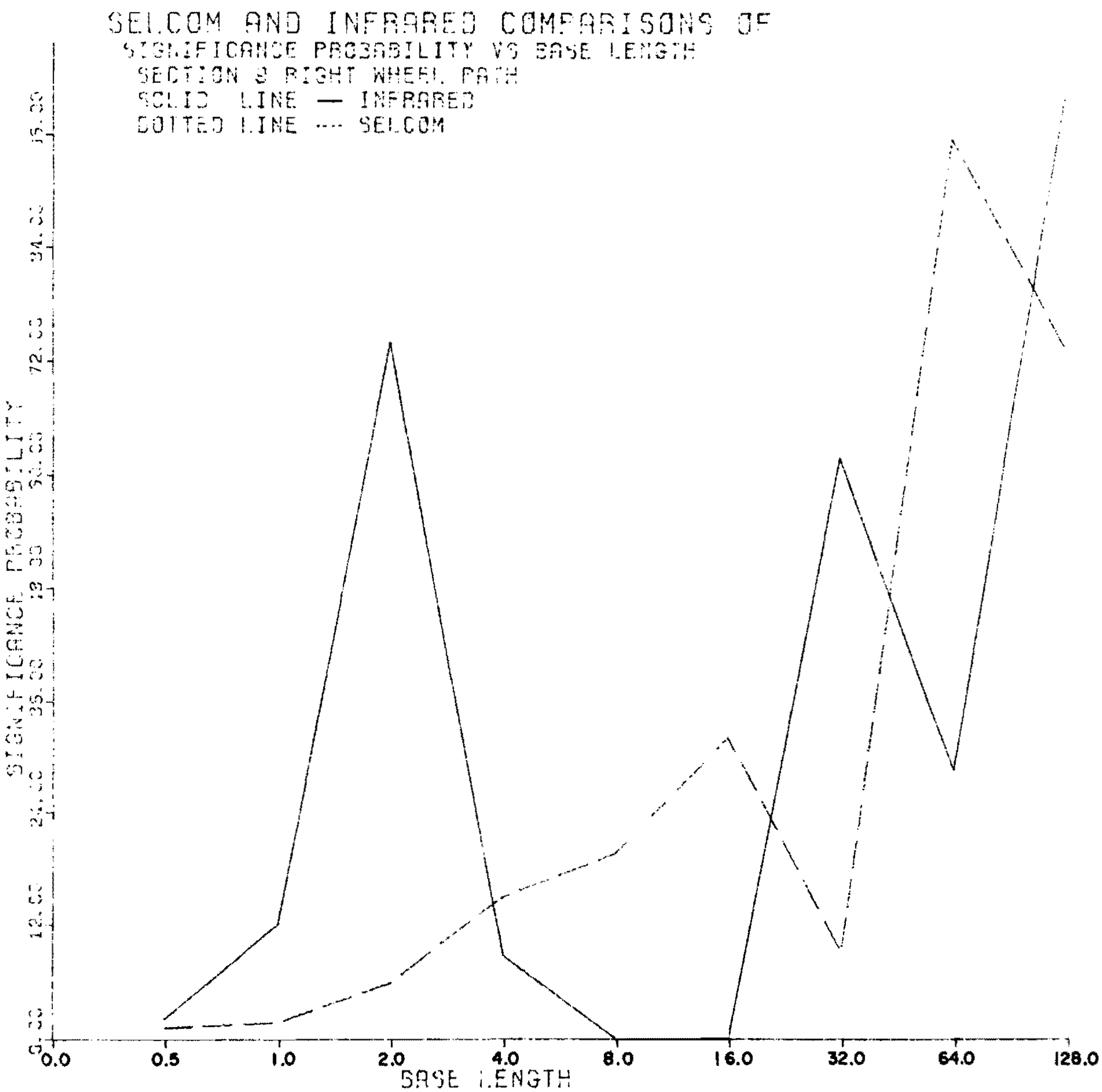
APPENDIX D

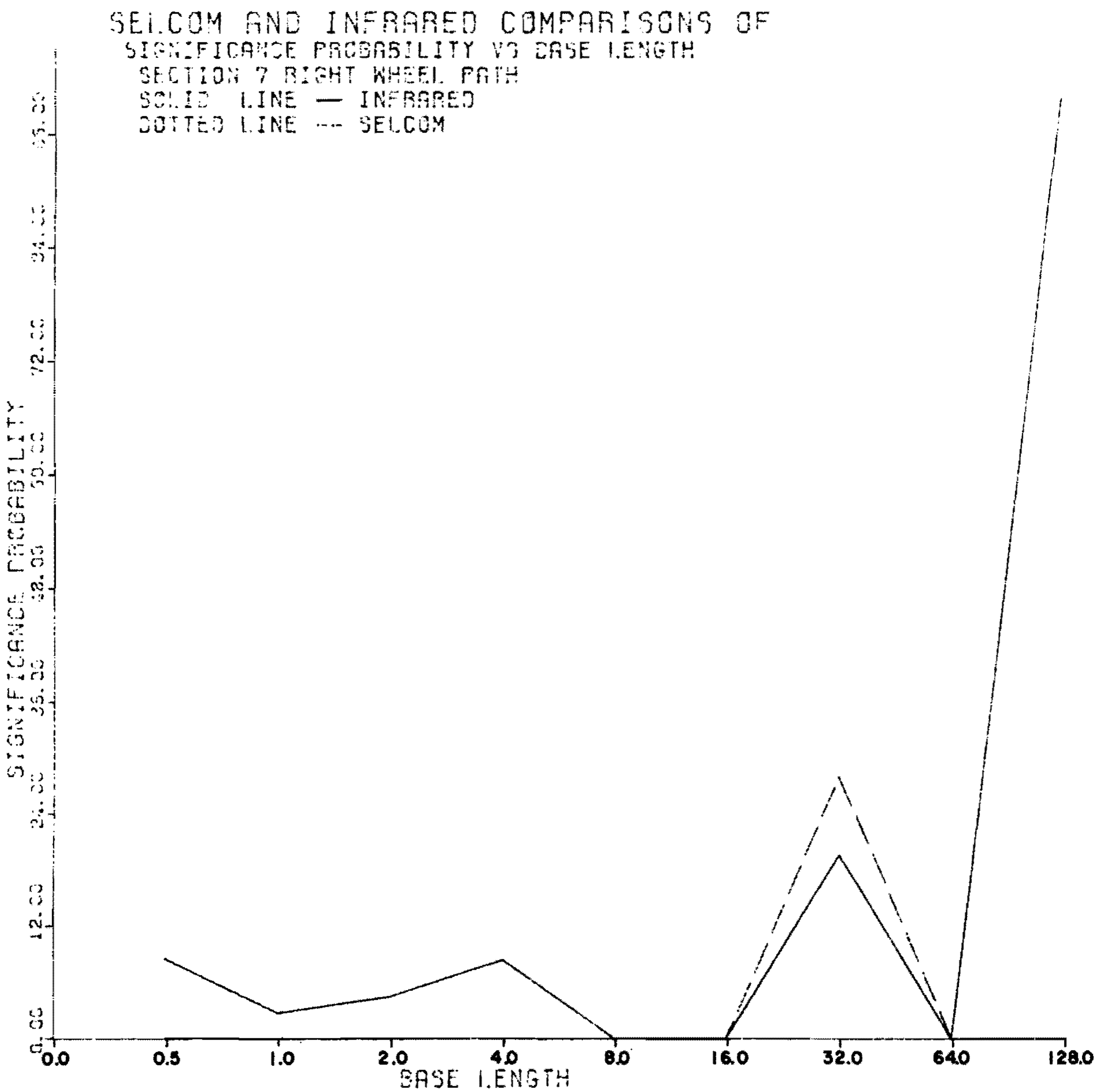
SIGNIFICANCE PROBABILITY VERSUS BASE LENGTH
FOR HO: 35 MPH = 50 MPH
SECTIONS 2, 6, 5, 9, 7 AND 32

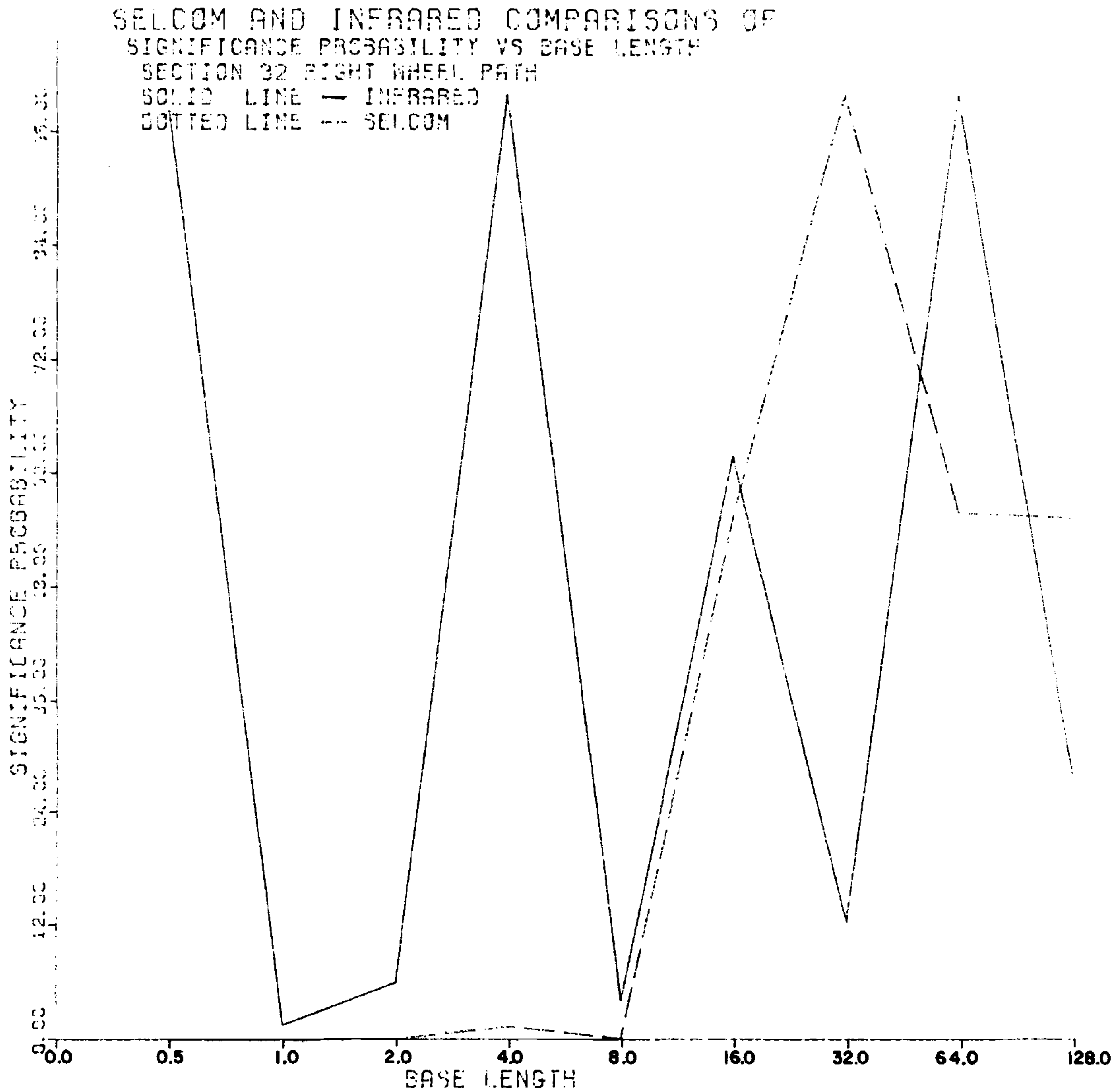

SELCOM AND INFRARED COMPARISONS OF
SIGNIFICANCE PROBABILITY VS BASE LENGTH
SECTION 2 RIGHT WHEEL PATH
SOLID LINE — INFRARED
DOTTED LINE -- SELCOM
SIGNIFICANCE PROBABILITY
72.00
12.00
0.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH

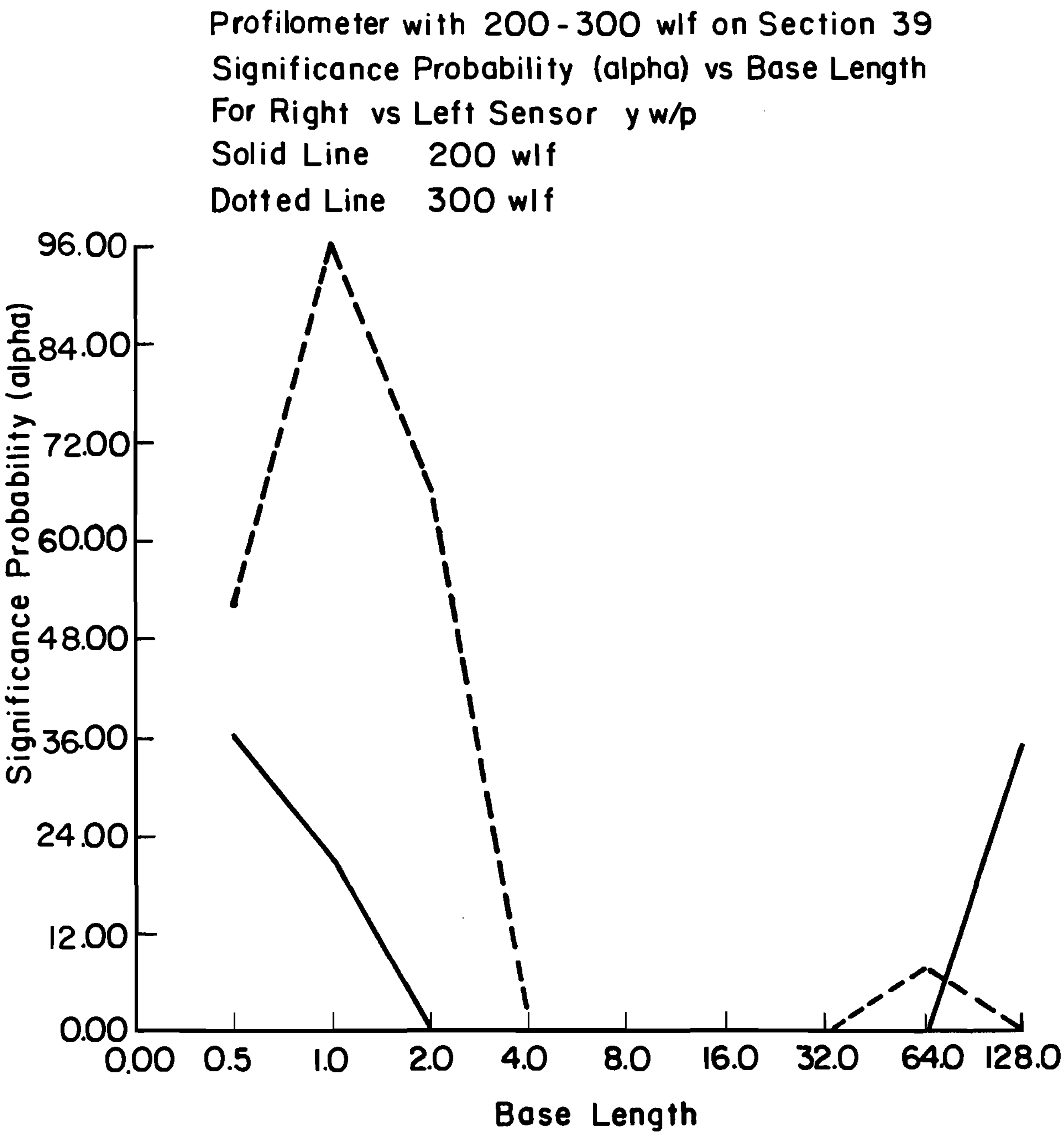

SELCOM AND INFRARED COMPARISONS OF
SIGNIFICANCE PROBABILITY VS BASE LENGTH
SECTION 6 RIGHT WHEEL PATH
SOLID LINE — INFRARED
DOTTED LINE -- SELCOM
SIGNIFICANCE PROBABILITY
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH


SELCOM AND INFRARED COMPARISONS OF
SIGNIFICANCE PROBABILITY VS BASE LENGTH
SECTION 5 RIGHT WHEEL PATH
SOLID LINE — INFRARED
DOTTED LINE -- SELCOM
SIGNIFICANCE PROBABILITY
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH


SELCOM AND INFRARED COMPARISONS OF
SIGNIFICANCE PROBABILITY VS BASE LENGTH
SECTION 8 RIGHT WHEEL PATH
SOLID LINE — INFRARED
DOTTED LINE --- SELCOM
SIGNIFICANCE PROBABILITY
72.00
84.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH


SELCOM AND INFRARED COMPARISONS OF
SIGNIFICANCE PROBABILITY VS BASE LENGTH
SECTION 7 RIGHT WHEEL PATH
SOLID LINE — INFRARED
DOTTED LINE -- SELCOM
SIGNIFICANCE PROBABILITY
0.00
12.00
72.00
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
BASE LENGTH


SELCOM AND INFRARED COMPARISONS OF
SIGNIFICANCE PROBABILITY VS BASE LENGTH
SECTION 32 RIGHT WHEEL PATH
SOLID LINE — INFRARED
DOTTED LINE -- SELCOM
SIGNIFICANCE PROBABILITY
BASE LENGTH
0.0
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0


Profilometer with 200-300 wlf on Section 39
Significance Probability (alpha) vs Base Length
For Right vs Left Sensor y w/p
Solid Line 200 wlf
Dotted Line 300 wlf
Significance Probability (alpha)
96.00
84.00
72.00
60.00
48.00
36.00
24.00
12.00
0.00
0.00
0.5
1.0
2.0
4.0
8.0
16.0
32.0
64.0
128.0
Base Length