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A study of the measurement of road roughness with the Mays Ride Meter (MRM) is presented in this report. A model is developed to interpret the effects of the long and short waves on the riding quality of the road and used to explain the difference between the Serviceability Indices obtained from the Surface Dynamics Profilometer (SDP) and the MRM.

In addition, a statistical analysis is used to show the degree to which the repeated runs of the MRM agree with each other. An assessment is then made as to the applicability of the MRM and its limitations.

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A STUDY OF THE PERFORMANCE OF THE MAYS RIDE METER

by

Yi Chin Hu
Hugh J. Williamson
B. Frank McCullough

Research Report 177-3

Development and Implementation of the Design, Construction
and Rehabilitation of Rigid Pavements

Research Project 3-8-75-177

conducted for

Texas
State Department of Highways and Public Transportation

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

by the

CENTER FOR HIGHWAY RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

January 1977

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PREFACE

This is the third in a series of reports that describe research performed in the project entitled "Development and Implementation of the Design, Construction, and Rehabilitation of Rigid Pavements." The project puts forth a long-range comprehensive research program to develop a system analysis of pavement design and management information system. The project is conducted through a National Cooperative Highway Research Program with the State Department of Highways and Public Transportation and the Federal Highway Administration.

An investigation of the performance of the Mays Ride Meter (MRM) is presented in this report. This study is directly related to the research, which involves the use of Mays Meter roughness measurements. The MRM study was begun when certain anomalies were observed in roughness measurements collected for use in project 177; the anomalies have been explained during the investigation. By virtue of the study presented herein, the research staff and others who use the MRM for research and field applications can use the roughness measurements with greater insight into the nature of the MRM measurements.

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LIST OF REPORTS

Report No. 177-1, "Drying Shrinkage and Temperature Drop Stresses in Jointed Reinforced Concrete Pavement," by Felipe R. Vallejo, B. Frank McCullough, and W. Ronald Hudson, describes the development of a computerized system capable of analysis and design of a concrete pavement slab based on drying shrinkage and temperature drop. August 1975.

Report No. 177-2, "A Sensitivity Analysis of Continuously Reinforced Concrete Pavement Model CRCP-1 for Highways," by Chypin Chiang, B. Frank McCullough, and W. Ronald Hudson, describes the overall importance of this model and makes recommendatins for efficient use of the computer program. August 1975.

Report No. 177-3, "A Study of the Performance of the Mays Ride Meter," by Yi Chin Hu, Hugh J. Williamson, and B. Frank McCullough, discusses the accuracy of measurements made with the Mays Ride Meter and their relationship to roughness measurements made with the Surface Dynamics Profilometer. January 1977.

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ABSTRACT

A study of the measurement of road roughness with the Mays Ride Meter (MRM) is presented in this report. A model is developed to interpret the effects of the long and short waves on the riding quality of the road and used to explain the difference between the Serviceability Indices obtained from the Surface Dynamics Profilometer (SDP) and the MRM.

In addition, a statistical analysis is used to show the degree to which the repeated runs of the MRM agree with each other. An assessment is then made as to the applicability of the MRM and its limitations.

KEY WORDS: Surface Dynamics Profilometer, Mays Meter, roughness, replication error, serviceability index, power spectrum.

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SUMMARY

The response of the Mays Ride Meter (MRM) to the roughness of the road is discussed in this report. Unlike the Surface Dynamics Profilometer, which measures the amplitudes of the waves, the MRM produces a single roughness measurement which relates to the vertical changes between the vehicle body and its rear axle. It, therefore, cannot reveal the type of roughness and is found to be unresponsive to the long waves. The swelling clay effects on the CRCP sample sections studied induced long roughness waves. This makes the Serviceability Indices (SI) of those sections obtained from the MRM differ greatly from the SI values from the Profilometer. A model was developed to separate the effects of long and short waves and were used to prove this explanation.

Despite the fact that it is not capable of measuring long waves, the MRM is shown is this study to produce highly repeatable roughness measurements. Moreover, measurements made on different days with different MRM's produce SI values which are in close agreement. Thus, the MRM should be considered an excellent device for measuring short waves only.

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IMPLEMENTATION STATEMENT

The Surface Dynamics Profilometer (SDP) is very capable of obtaining an accurate roughness evaluation of the road. However, the equipment itself and its operation are extremely expensive. The Mays Ride Meter (MRM), another device for measuring the Serviceability Indices of the road sections, is less expensive and more handy to operate, but it is not so accurate and it does not provide so much roughness information. Therefore, it is worthwhile to investigate the applicability and the limitations of the MRM so that it can be used properly.

In this report, the response of the MRM to different types of roughness waves is investigated. It is shown that the MRM is responsive primarily to short waves, while the SDP is capable of measuring roughness with a wide range of wavelengths. In view of the excellent repeatability of the MRM and the agreement between the measurements made by different MRM's, however, the point above does not invalidate the MRM; it simply means that the Mays Meter should be thought of as a device for measuring short waves only.

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CHAPTER 1. INTRODUCTION

BACKGROUND AND OBJECTIVES

The Mays Ride Meter (MRM) is a device which can be used to estimate the serviceability of the road by measuring the vertical changes between the vehicle body and its rear axle as the vehicle travels over a pavement. The mechanical details of the device, the measuring technique, and the calculation of a Serviceability Index (SI) from the MRM roughness index are discussed in Ref 1.

A set of roughness measurements were made on IH-45 near Huntsville, Texas to study the effects of swelling clay distress on the pavement's condition. Both the Surface Dynamics Profilometer (SDP) (Refs 1 and 2) and the Mays Ride Meter were operated on those sections. Large discrepancies between the serviceability indices obtained from the two measuring devices were observed. This study was originated to explain the nature of these differences and the implications regarding the meaningfulness of the roughness measurements made by the less expensive Mays Meter.

An additional set of test sections of a more diverse nature were also included in the study so that the results would have general applicability.

In addition to the physical meaningfulness of the measurements, the run-to-run repeatability and the consistency between serviceability indices obtained from measurements made with different Mays Meters on different days were also analyzed.

SCOPE OF THE STUDY

In Chapter 2, a comparison is made between the SI values obtained by using measurements from both the General Motors Surface Dynamics Profilometer and the Mays Ride Meter. A sample of continuously reinforced concrete pavement (CRCP) road sections on IH-45 near Huntsville were selected for study because their particular roughness patterns illustrate certain consistent differences between the SI values obtained from the two devices. The SI differences are explained on the basis of the responses of the two instruments to roughness with different wavelengths.

In Chapter 3, the response of the Mays Meter to long and short waves on flexible pavements is discussed. Additionally, a study of the repeatability of the Mays Meter was made, and an analysis was made to determine whether the MRM is more repeatable on smooth sections than on sections with pronounced roughness.

The models developed in Chapter 2 to investigate the effects of roughness of different wavelengths are presented in Appendix 1. Calibration curves used to convert the MRM roughness measurements to SI values are presented in Appendix 2, and the Mays Meter replication error data analyzed in Chapter 3 are presented in Appendix 3. The conclusions and recommendations are discussed in Chapter 4. The comparison of replication errors on the smooth and rough sections is presented in Appendix 4, and the correction of certain errors in a previous report which relate to this study is discussed in Appendix 5. Although an extensive discussion of MRM operation is given in Ref 1, a brief summary of certain aspects of MRM measurement which bear significantly on the results is given in Appendix 6.

CHAPTER 2. THE DIFFERENCE BETWEEN SI VALUES FROM THE PROFILOMETER AND THE MAYS METER ON THE HUNTSVILLE SECTIONS

In this chapter, the difference between the SI's from the Profilometer and the Mays Meter is discussed. Because of the different characteristics of the two measuring devices, they respond differently to the long and short waves of a road surface. A model is set up to substantiate this explanation. By studying the specific sections discussed in this chapter, we can obtain a better understanding of the reactions of the two devices to the roughness of the road in general.

CHARACTERISTICS OF THE ROAD

The CRCP sample sections are near Huntsville on IH 45 in the northbound outside lane. Patching has been done continually on the sections. The swelling clay effect is very serious in the northern part of the road, and it appears sporadically in the southern part. Although the sections do not extend so far to the north, they are very much influenced by the swelling clay effects in the subgrade.

COMPARISON OF SI's FROM THE TWO DEVICES - SDP AND MRM

The Mays Meter SI's (SI_m) have a small range of 3.1 to 3.5, while the Profilometer SI's (SI_p) vary from 2.5 to 5.0. The plot of ($SI_p - SI_m$) against SI_p is shown in Fig 2.1. The linear nature of the plot is due to the small variation on SI_m which causes the ($SI_p - SI_m$) versus SI_p plot to resemble an (SI_p - constant) versus SI_p function.

The difference in SI's from the two devices can be explained by their different responses to the roughness waves. The Mays Meter measures the roughness of the road by the vertical movement between the vehicle body and its rear axle. Therefore, the value measured is largely dependent upon the suspension system of the vehicle. Generally, however, the movement of the axle relative to the body is greater when passing over a short wave than when passing over a long wave with the same amplitude. That is to say, the

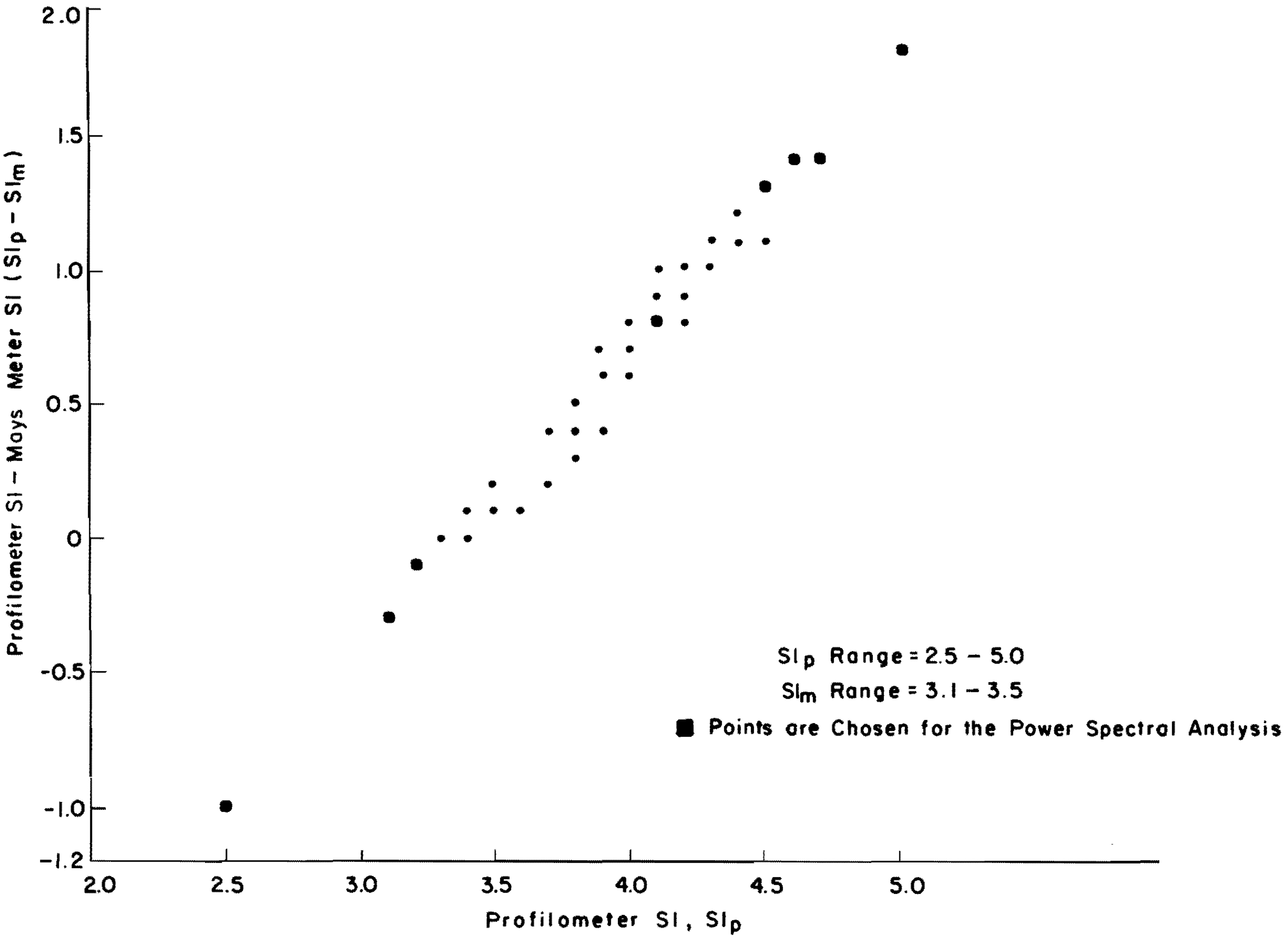


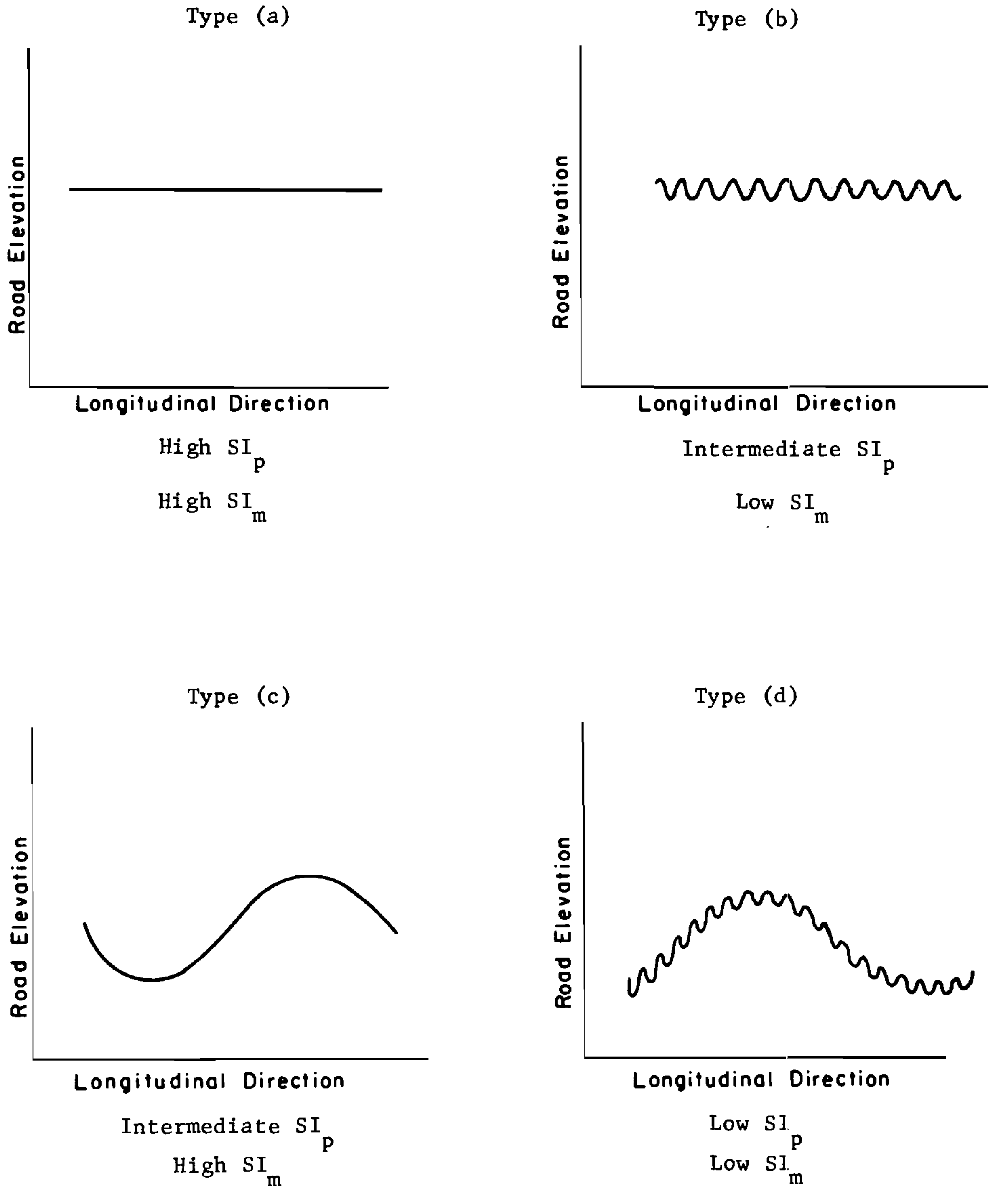
Fig 2.1. $(SI_p - SI_m)$ versus SI_p for Huntsville sections.

Mays Meter can detect the short roughness waves, but it is relatively insensitive to the long waves due to the characteristics of the vehicle. The profilometer, on the other hand, takes into account both the long and short waves of the pavement roughness. Thus, the SI_p's and SI_m's will differ according to the nature of the roughness. Fig 2.2 gives four types of hypothetical road profiles. A real road profile will be a combination of these ideal cases. The sections categorized as type (b) will likely have relatively low amplitudes for long waves and relatively high amplitudes for short waves, while the type (d) will likely have relatively high amplitudes for both long and short waves.

The uppermost points in Fig 2.1 are expected to approach type (b) and the lower extreme points are expected to approach type (d). Thus, the difference can be detected by the profilometer but not by the Mays Meter. Those upper and lower extreme points (the points with "x" in the figure) were chosen for amplitude analysis. The expected result is a large difference in the amplitudes of the long waves and a small difference in those of short waves between those sections with high SI_p's and low SI_p's. Fig 2.3 is an example of the analysis of amplitude; the figure shows the amplitude for each frequency band of the sections with the highest and the lowest SI_p's are systematically lower than those of the sections with low SI_p's. However, those road profiles cannot be categorized into any of the four types by comparing the measured differences between the amplitudes of each frequency band alone. It must be realized that both the riders' subjective sensation and the roads' objective quality should be considered when trying to study the serviceability of the road section. While the amplitudes describe the roughness in strictly physical terms, they are not easily interpreted in terms of riding quality. This is because a rise and fall in the road surface of, for instance, 1.0 inch can cause a very severe or an unnoticeabile riding sensation depending on its wavelength. It is necessary to find a simple index showing how the physical quality affects the riding quality of the road for the long and short waves.

ANALYSIS OF THE POWER SPECTRUM

A power spectral value is simply the square of a roughness amplitude divided by a constant (the bandwidth). The amplitude describes the severity



High SI_p
High SI_m

Intermediate SI_p
Low SI_m

Intermediate SI_p
High SI_m

Low SI_p
Low SI_m

Fig 2.2. Hypothetical road profiles and the corresponding SI's.

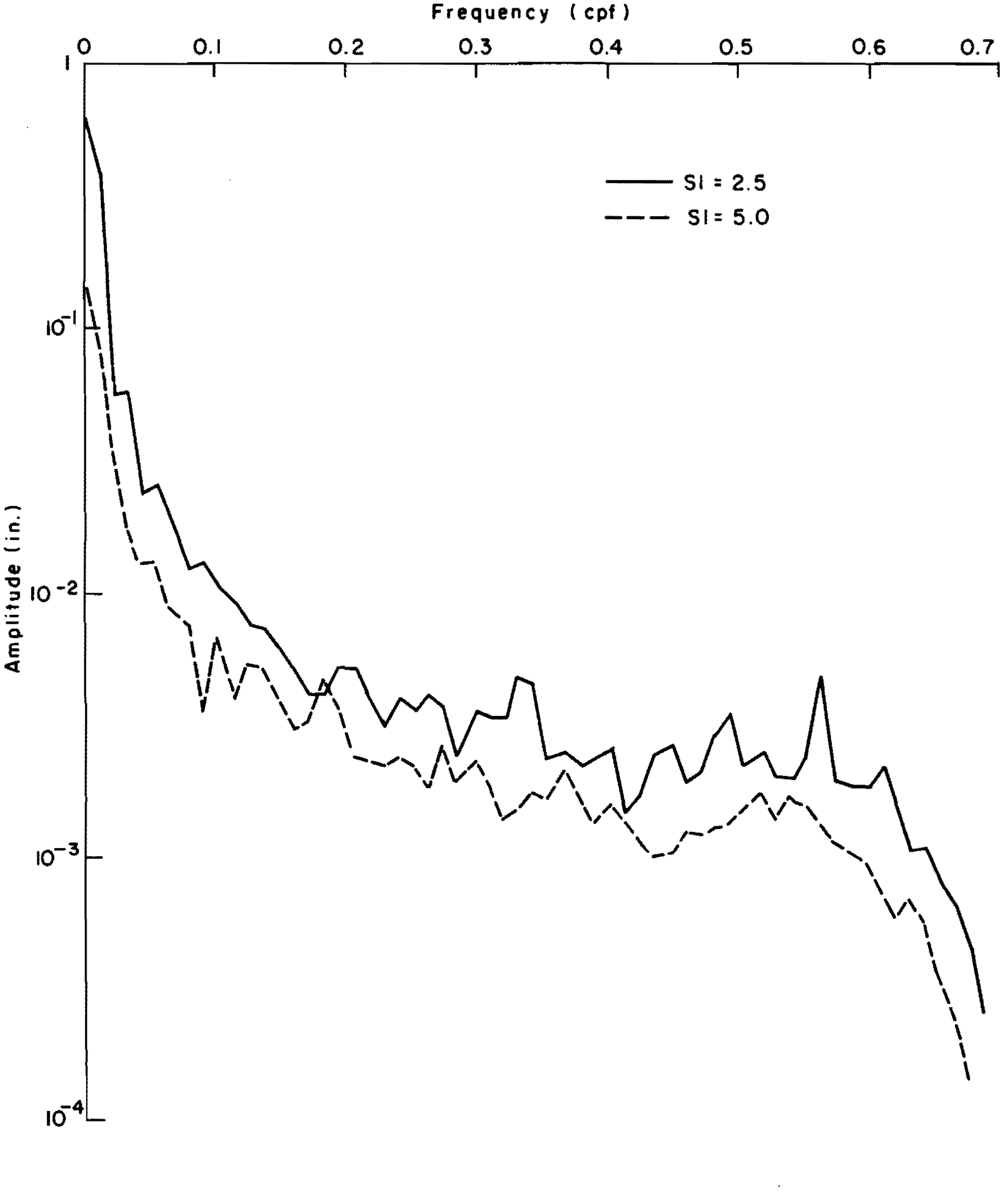


Fig 2.3. Amplitudes of the roughness waves versus the frequency.

of the roughness waves within a band of wavelengths. In Ref 2, the power spectral values of nineteen sections with PSR from 4.0 to 4.5 and of ten sections with PSR from 2.0 to 2.5 were averaged for each frequency band. The results are shown in Table 2.1. The two sets of road sections with the power spectra in the table should have SI's of 4.25 and 2.25, respectively, on the average. The SI is a composite effect of roughness for each frequency band. Thus, if a road has power of 1.2945 at wavelength 86 feet,(or, equivalently, frequency 0.012 cycles per foot) it can be said that the road has roughness in the range of 86 feet in wavelength comparable to that of an average road with an SI of 4.25. Similarly, if the power value is 2.6602, then the road is comparable to an average road with 2.25 SI with respect to 86-foot-long roughness waves. The same analysis can be applied to the power spectral values for the roughness of other wavelengths, and the composite effect of SI for each frequency band mades the overall SI. If the relationship between the power and the SI can be found, the SI for each frequency band can be obtained by interpolating. Thus, the effect of high and low frequency waves on the riding quality can be shown.

Using the two points on the power versus frequency curve for each of the ten frequencies listed in Table 2.1 and the assumed point, SI = 5.0 if the power is zero, we can use piecewise linear interpolation to convert each power value to a corresponding SI value. The assumption of SI = 5.0 if the power is zero is justified by the fact that the power can only be zero if there is no roughness at the particular wavelength in question. While this approach is somewhat crude because of the small number of points available on the power versus frequency curves, it will be seen that the interpolated SI values are much more easily interpreted than the power or amplitude values. Thus, the linear interpolation approach is adequate for the specific comparisons we wish to make. The curves for each frequency band can be found in Appendix A.

RESULTS

Table 2.2 shows the interpolated SI for each frequency band of the sections that appeared as the extreme points in Fig 2.1. The four sections on the left side of the table are those with SI_p lower than SI_m, while the right five sections are those with SI_p much greater than SI_m. The SI_m's for all

TABLE 2.1. AMPLITUDE STATISTICS FOR PSR LEVELS*

Frequency (cpf)	Power Mean (in^2/cpf)	Approximate Amplitude for Upper 3σ (inches)
PSR INTERVAL 4.0 TO 4.5 (19 SECTIONS)		
0.012	1.2945	1.4134
0.023	0.0520	0.2833
0.035	0.0159	0.1566
0.046	0.0076	0.1085
0.058	0.0044	0.0823
0.069	0.0028	0.0661
0.081	0.0025	0.0617
0.092	0.0022	0.0580
0.104	0.0018	0.0526
0.116	0.0017	0.0516
PSR INTERVAL 2.0 TO 2.5 (10 SECTIONS)		
0.012	2.6602**	2.0262
0.023	0.2538	0.6258
0.035	0.0759	0.3422
0.046	0.0307	0.2176
0.058	0.0249	0.1960
0.069	0.0174	0.1641
0.081	0.0108	0.1291
0.092	0.0087	0.1161
0.104	0.0082	0.1127
0.116	0.0084	0.1140

*These power spectra are presented in Ref 3, page 18.

**See Appendix 5.

TABLE 2.2 INTERPOLATED SI FOR EACH FREQUENCY BAND, HUNTSVILLE SECTIONS, FEBRUARY 1974, CRCP CONCRETE SECTIONS

		$SI_p < SI_m$ (Type d)				$SI_p > SI_m$ (Type b)				
	SI_p	2.5	3.1	3.1	3.2	4.1	4.5	4.6	4.7	5.0
	SI_m	3.5	3.4	3.4	3.3	3.3	3.2	3.2	3.3	3.2
Wavelength (feet)	Frequency (cpf)									
86.5*	0.012	0.9	2.0	4.4	1.1	4.3	3.9	4.8	4.8	4.8
43.2	0.023	3.3	0.0	3.2	2.3	3.6	3.5	4.2	4.0	4.1
28.8	0.035	1.6	1.6	2.6	1.9	4.0	3.4	3.6	3.7	4.3
21.6	0.046	2.7	2.0	1.8	2.1	3.6	4.4	4.0	3.8	4.2
17.3	0.058	2.0	0.0	3.0	3.0	3.8	4.3	4.1	3.6	3.9
14.4	0.069	2.6	1.3	3.8	3.2	4.0	4.4	4.1	3.6	4.1
12.4	0.081	3.1	2.0	4.0	3.4	4.4	4.4	3.9	3.0	4.2
10.8	0.092	2.2	4.2	3.8	3.5	4.6	3.9	4.1	3.8	4.6
9.61	0.104	3.3	3.7	4.1	3.9	4.5	4.2	4.2	3.8	4.1
8.65	0.116	3.7	2.9	4.1	4.2	4.5	4.1	4.3	4.1	4.7

SI_p = overall serviceability index for the pavement section obtained from profilometer

SI_m = overall serviceability index for the pavement section obtained from Mays Meter

*See Appendix 5

of these sections are about the same. It can be seen that the SI's are high and uniform on the right side of the table. On the left side, the SI's are much more varied. By examining the pattern of SI variation with wavelength for these sections with lower SI_p values, the discrepancy in the SI_p and SI_m ranges is explained.

Notice that, for the four sections with low SI_p's, we have generally lower interpolated SI values for long wavelengths than for short wavelengths. This statement is substantiated by the following observations:

(1) For the two shortest wavelengths, 8.65 and 9.61 feet, the lowest SI value is 2.9 and the other seven SI's are 3.3 or above. For the five wavelengths of 14.4 feet or shorter, only three of the twenty SI values are less than 2.5.

(2) For the five larger wavelengths, from 17.3 to 86.5 feet, each road section has an SI value below 2.0 (see Appendix 5), and thirteen of the twenty SI values are less than 2.5.

Thus, we see that the differences in SI_p values for these nine sections are explainable in terms of variations in long roughness waves. The probable physical cause is the nonuniform presence of a swelling subgrade. It appears that the Mays Meter is not responsive to these variations in long waves. Thus, the SI_m values have a very samll range, reflecting the smaller section-to-section variation in short-wavelength roughness.

CHAPTER 3. PERFORMANCE OF THE MAYS ROAD METER ON FLEXIBLE PAVEMENT

In the previous chapter, a set of CRCP test road sections with swelling clay distress were used to illustrate certain differences between the Mays Road Meter and the profilometer. Because of the comparable quality of these sections with respect to short roughness waves, the SI_m values varied within a narrow range. The range of SI_p values is considerably larger, however, because of variations in the long waves. While the special characteristics of these test sections serve to illustrate clearly certain differences between the two instruments, it was felt that the results should be supplemented with a study of a more typical set of pavements with a wider range of SI_m values. Also, it is worthwhile to compare the results for flexible pavements. The Austin test sections were adopted for the reasons stated above.

In this chapter, the approach used in Chapter 2 will be used to study the differences between SI_p and SI_m. Also a study of the repeatability of the Mays Meter and the analysis of variance from the repeated runs of the Mays Meter will be made.

AUSTIN TEST SECTIONS

The Austin test sections consist of 28 sample sections taken from the roads around the city of Austin to calibrate the Mays Meter roughness measurements so they can be converted to SI values. Unlike the sections discussed in Chapter 2, which were taken from a single highway characterized by swelling clay distress, the test sections are typical pavements from all types of roads, i.e. interstate highways, state highways, and farm roads. They are flexible pavements with SI from high to low.

STUDY OF SI_m AND SI_p

Different from that of the Huntsville sections, the plot of $(SI_p - SI_m)$ against SI_p for the Austin test sections scatters randomly (Fig 3.1). This is

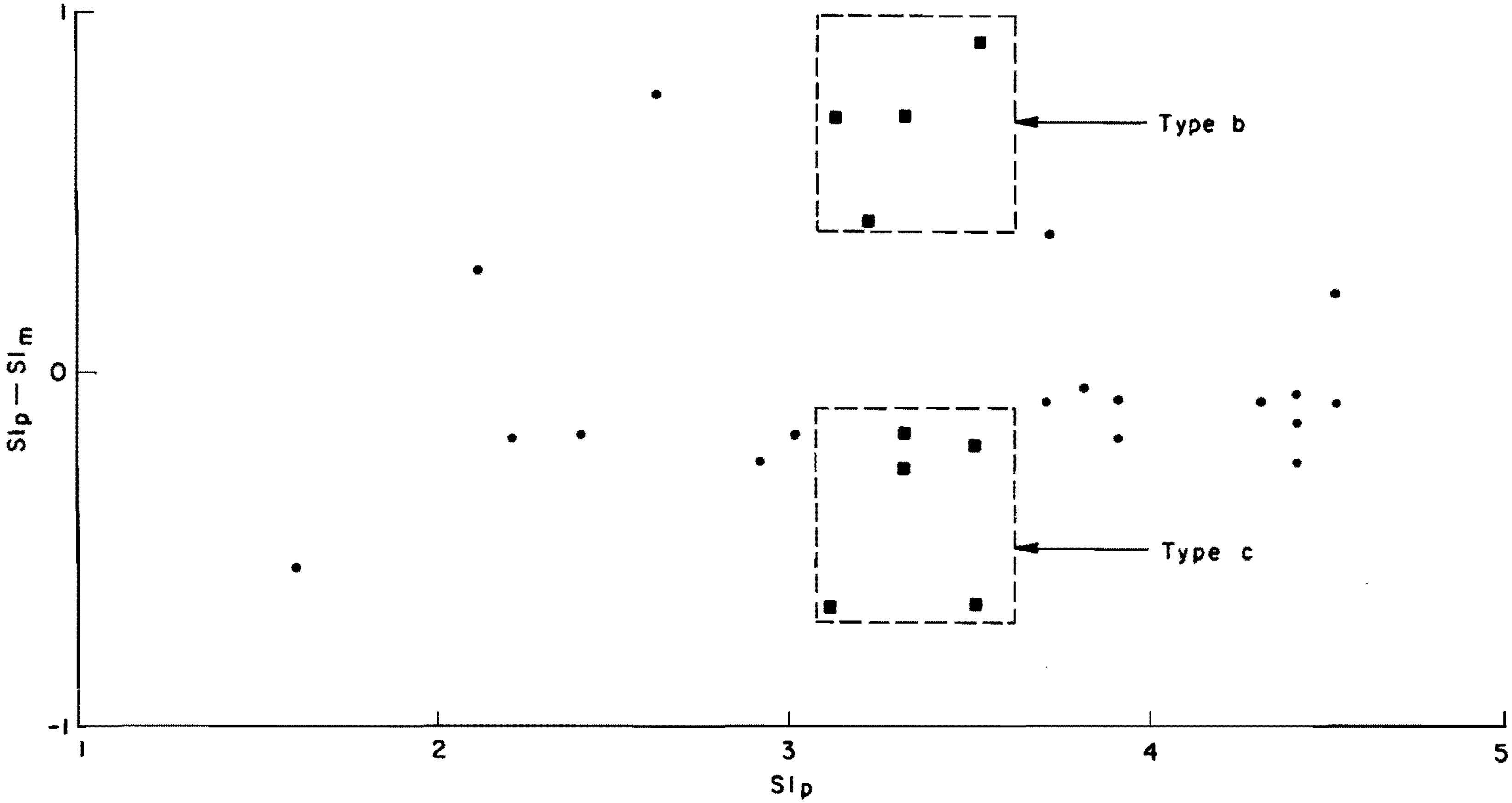


Fig 3.1. $(SI_p - SI_m)$ versus SI_p for Austin test sections.

because these are the sections used to calibrate the SI. The difference between the SI_p and the SI_m is actually the residual of the fitting curve, and Fig 3.1 is a residual plot of the fitting.

Since there are no obvious extreme points, the analysis was made for the points in the upper and lower parts of the graph. For the purpose of comparison, it is desirable to investigate how the Mays Meter responds to the sections with similar SI_p. Therefore, the upper and lower points in the band of $SI_p = 3.1 - 3.5$ of Fig 3.1 were chosen.

Since the Mays Meter responds to short waves only, the interpolated SI for the short waves of those sections with low SI_m should be smaller than those with high SI_m. With similar SI_p, the sections with low interpolated SI for the short waves should have high interpolated SI to allow the long waves to balance the short waves. That is to say, the sections with high SI_m approach type (c) while those with low SI_m approach type (b) (see Fig 2.2).

Table 3.1 shows the SI from the interpolation for each frequency band of the sections chosen. Comparing the left ($SI_p > SI_m$) and right ($SI_p < SI_m$) parts of the table, the following results can be seen:

(1) Consistently with the results of the previous chapter, again there is evidence that the short waves are weighted more heavily in SI_m than in SI_p. This is seen by the fact that the interpolated SI values for the short waves are systematically lower if $SI_p > SI_m$ (left of the table) than if $SI_p < SI_m$ (right of the table). For the five wavelengths of 14.4 feet or shorter, all the SI on the right are 4.2 or above, and eight of twenty-five are greater than or equal to 4.5, while all of the corresponding SI on the left are less than 4.2, and eleven out of twenty are lower than 4.0.

(2) The SI_p values for all the sections included in Table 3.1 vary within narrow range. Thus, since the SI for short wavelengths are lower on the left, it might be expected, since SI is a composite of long and short waves, that the SI for long waves would be lower on the right. This does not seem to be true, but it must be remembered that SI_p is a very complex function of the roughness amplitudes; an SI higher by 0.1 for the short waves cannot be expected necessarily to be balanced by an SI lower by 0.1 for the long waves (Appendix 5).

(3) It should not be alarming that the SI_m value is sometimes lower than any of the SI values for the short waves. The SI_m is affected by waves shorter than 8.65 feet, for which an interpolated

TABLE 3.1. INTERPOLATED SI VALUES FOR AUSTIN TEST SECTIONS
NOVEMBER 21, 1974 D-10 MRM

		$SI_p > SI_m$ (Type d)				$SI_p < SI_m$ (Type c)				
	SI_p	3.50	3.30	3.10	3.20	3.30	3.50	3.30	3.50	3.10
	SI_m	2.59	2.60	2.40	2.78	3.48	3.71	3.57	4.15	3.75
	$SI_p - SI_m$	0.91	0.70	0.70	0.42	-0.18	-0.21	-0.27	-0.65	-0.65
Wavelength (feet)	Frequency (cpf)									
86.5*	0.012	3.2	1.6	3.1	1.3	1.3	3.6	1.2	3.0	4.5
43.2	0.023	4.2	3.1	3.7	3.9	3.7	4.2	3.4	4.2	3.7
28.8	0.035	3.7	3.5	3.4	4.1	4.2	4.2	3.0	4.1	2.7
21.6	0.046	3.0	3.8	3.2	4.3	4.2	4.5	3.4	4.3	2.8
17.3	0.058	4.1	4.2	4.1	4.2	4.4	4.3	4.4	4.6	4.4
14.4	0.069	4.0	4.0	3.6	4.1	4.2	4.2	4.2	4.2	4.5
12.4	0.081	4.1	4.1	3.5	3.8	4.2	4.3	4.2	4.6	4.4
10.8	0.092	3.6	4.1	3.6	3.3	4.4	4.3	4.2	4.2	4.5
9.61	0.104	3.9	4.1	3.6	3.7	4.4	4.3	4.2	4.3	4.5
8.65	0.116	3.9	4.1	4.0	3.6	4.7	4.6	4.4	4.8	4.6

SI_p = overall serviceability index for the pavement section obtained from profilometer

SI_m = overall serviceability index for the pavement section obtained from Mays Meter

*See Appendix 5

SI value is not obtainable. The amplitudes of these short waves are correlated with, but not direct functions of, the amplitudes of the 8.65 foot-long waves.

It must be emphasized that, crude as this piecewise linear model may be, it does give us a better interpretation of how roughness affects the riding quality than do the roughness amplitudes, and it does show how the Mays Meter reacts to short and long waves of the road profile.

REPEATABILITY OF THE MAYS METER

The "repeatability" of an instrument refers to the degree to which the repeated measurements made with the instrument agree with each other. The Mays Meter gives a different roughness value for each run due to the different wheelpaths traversed and the random error from the measuring device. If the measured values from the repeated runs have a large variance, the repeatability will be low. On the other hand, if the variance is small, the repeatability will be high.

There were four repeated runs of the Mays Meter for each section. (The Mays Meter was operated five times on each section and the most deviate one was discarded. Thus, the variance estimates computed here are actually slightly too low.) The SI_m value is calculated by employing the average of four Mays Meter readings and an empirical relationship between the Mays Meter reading and the serviceability (Ref 1). The same relationship, however, can be used to compute a serviceability index for each individual Mays Meter reading. The tables which give the corresponding Mays Meter reading value and the SI_m for both the D-10 and the D-21 Mays Meters are shown in Appendix 2.

Now, the run-to-run variation in the SI_m values is used to assess the repeatability of the Mays Meter measurements. To do this, the value E is computed such that the probability is 0.95 that the replication error in the SI_m on a single section is less than E. Thus, E is a 95 percent upper confidence limit for the magnitude of the error. The derivation and the calculation of E can be found in Appendix 3. Figures 3.2 and 3.3 show the distribution curve of the E values for D-21 and D-10 Mays Meters, respectively. The following results were obtained:

(1) The mean of E for the D-21 Mays Meter is 0.152. From Fig 3.2, the median of E is 0.15 and 90 percent of the E values are less than 0.225.

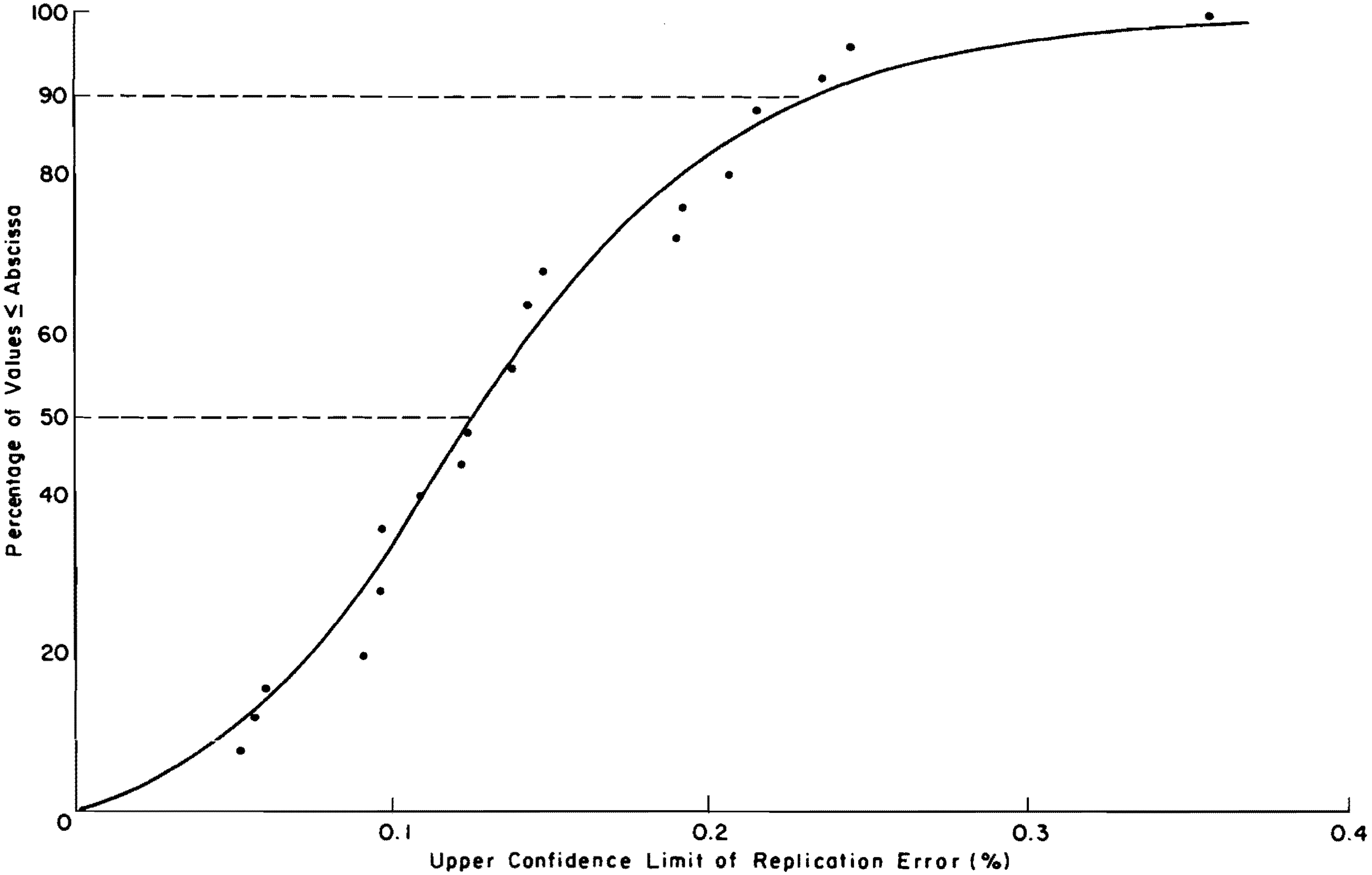


Fig 3.2. Distribution of upper confidence values of replication errors in single Mays Meter runs: October 22, 1974, B-10 MRM.

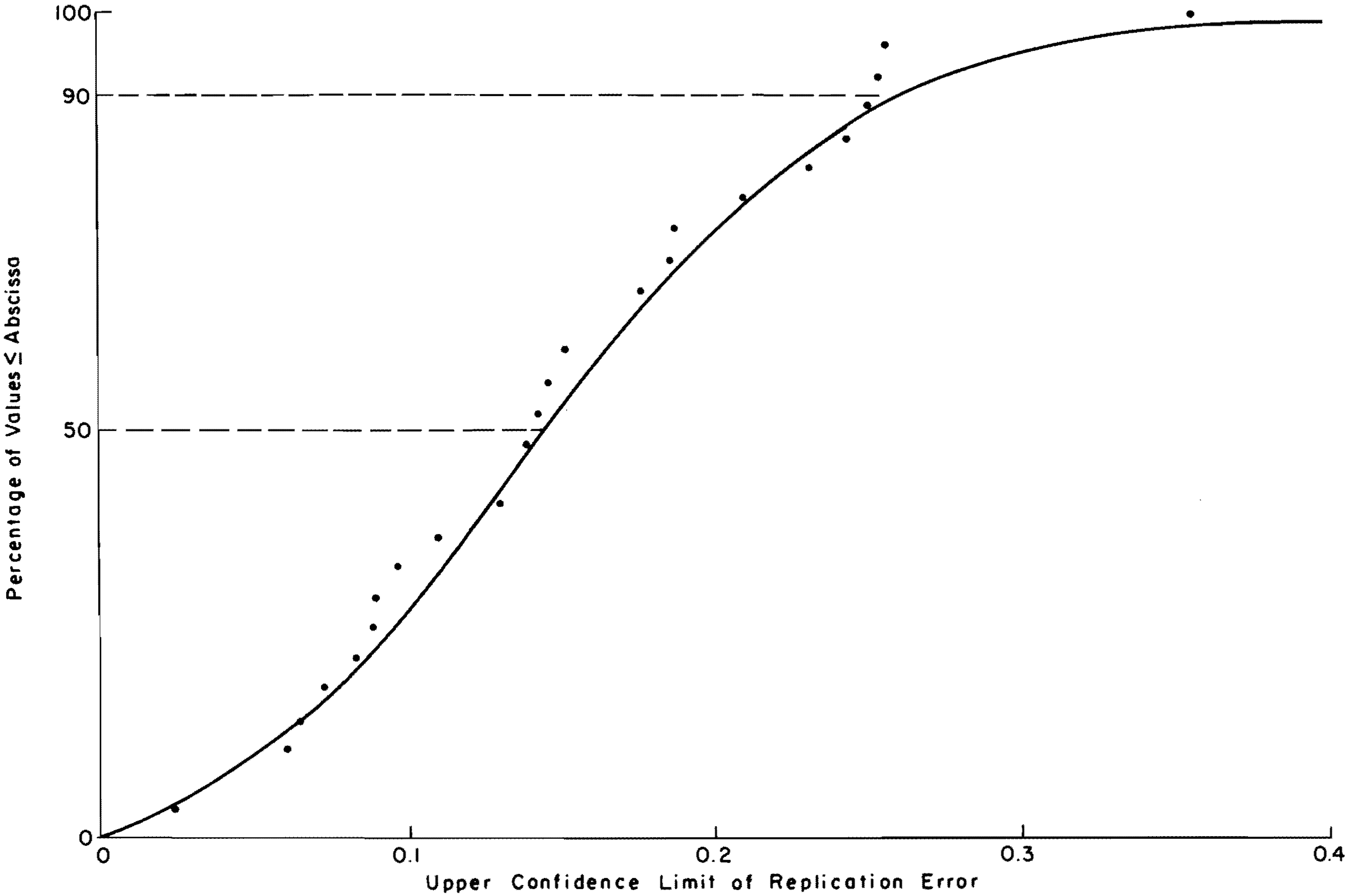


Fig 3.3. Distribution of upper confidence values of replication errors in single Mays Meter runs: November 21, 1974, D-10 MRM.

(2) The mean of E for the D-10 Mays Meter is 0.143. From Fig 3.3, the median is 0.145 and 90 percent of the E values are less than 0.255.

From these results, it was concluded that both the D-10 and the D-21 Mays Meters are measuring devices with extremely high repeatability.

COMPARISON OF THE REPLICATION ERROR AND VARIANCE WITH RESPECT TO SI_p

When a road has just been constructed, the surface is smooth in both the longitudinal and transverse directions. The probability that a large difference will exist between two runs is very small. For an older, deteriorated pavement, more transverse road-surface irregularities would be expected so that small variations in the path followed by the vehicle can cause large differences in the roughness which will be measured. The replication error, is therefore expected to be larger for a section with low SI_p than for one with high SI_p.

Figure 3.4 shows the plot of the 95 percent upper confidence limit of the replication error against the mean of the two profilometer runs (on October 22, 1975, and November 11, 1974). No specific trend is detected as the SI_p gets larger. In view of the relatively small number of repeated runs on each section, this unexpected result can probably be attributed to sampling error.

In the analysis above, the conficence limits were computed for each road separately. In doing this, allowance was made for the possibility that the error distributions might vary from road to road. It is also possible, however, to combine or pool the variance estimates for a set of road sections to obtain an overall error-variance estimate.

The procedures in testing the hypothesis that the replication variances for the road sections with high and low SI are equal can be found in Appendix 4. The results are shown in Table 3.2.

The F tests show no significant differences between the variances for either machine. The hypothesis that the variances for those sections with high and low SI are equal cannot be rejected. A significant result, however, would be expected if the sample size were larger.

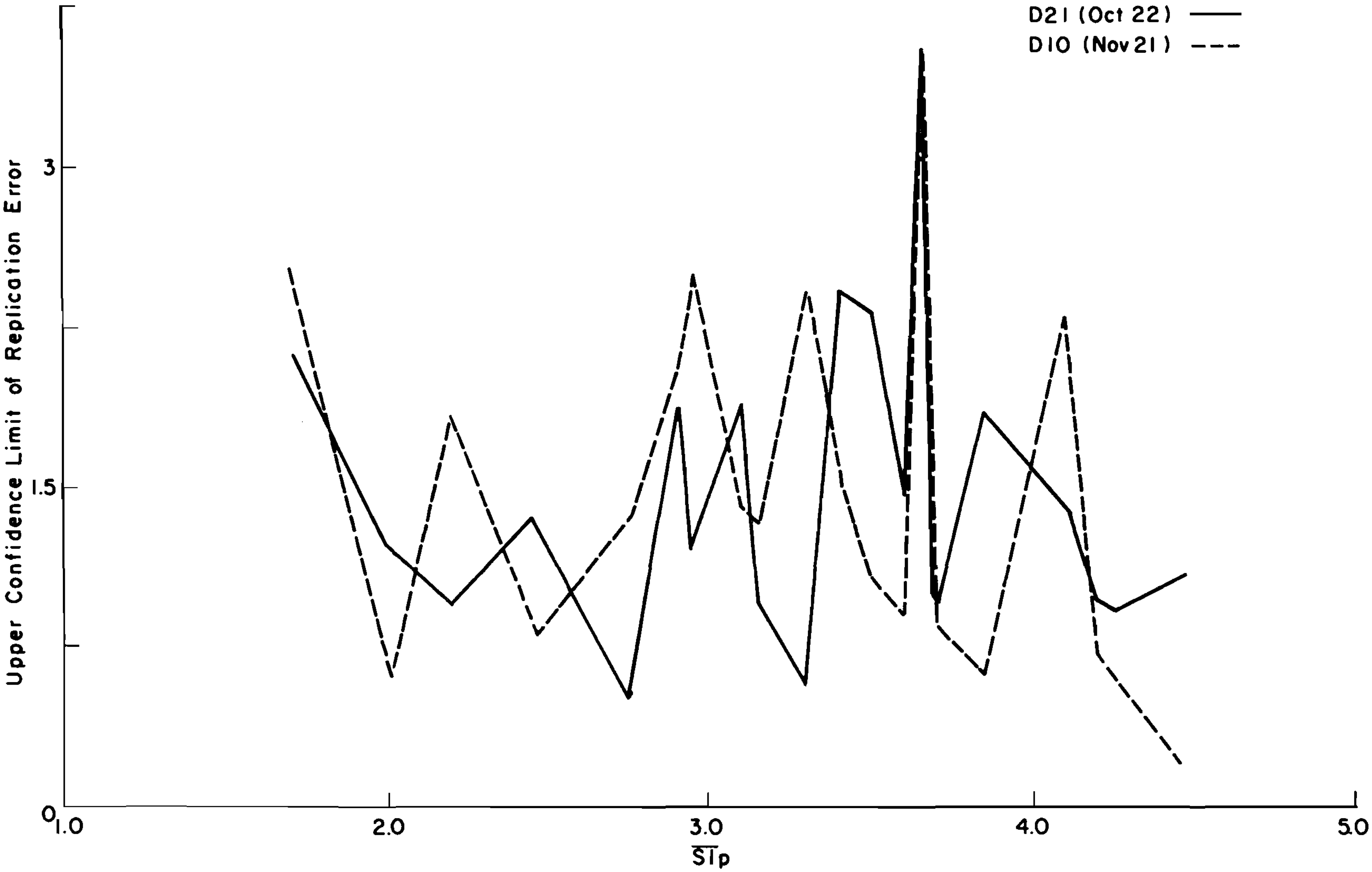


Fig 3.4. E values versus the corresponding $\overline{SI}_p$.

TABLE 3.2. F-TEST FOR THE POOLED REPLICATION VARIANCES FOR THOSE SECTIONS WITH HIGH AND LOW RIDING QUALITY

Mays Meter	PSI_p	Number of Sections	Pooled Variance	d.f.	F
D-10	4.0 and above	6	0.009459	18	1.14(<2.34)
	2.5 and below	4	0.010798	12	
D-21	4.0 and above	4	0.009787	12	1.37(<2.48)
	2.5 and below	5	0.007152	15	

"d.f." = "degrees of freedom."

THE COMPARISON OF THE D-10 AND D-21 MAYS METERS

The Response on the Roughness of the Pavement

Because of the different dates of operation of the D-10 and D-21 Mays Meters (November 21, 1974, and October 22, 1974, respectively), the SI used to calibrate the SI_m are not necessarily the same. Table 3.3 is set up for those sections with at most 0.1 difference in SI_p to observe how the SI_m relate to each other and how they relate to the SI_p.

Notice that generally the SI_m are both higher or both lower than the SI_p. The only section that does not agree with this rule (Section 41) has very small differences (0.01 and .12) between the SI_p and the SI_m. This general trend is again attributed to the type of roughness of the section. If the section is characterized by short waves, both the machines will indicate SI_m lower than SI_p. If the short waves are not so significant the long waves, both will give SI_m higher than SI_p. It can be concluded that the two devices respond consistently to the different types of roughness.

The Difference Between Pooled Variances

The pooled error variances for the D-21 and D-10 Mays Meters are shown in Table 3.4. As expected, the F test shows no significant difference in the variances between the D-21 and D-10 Mays Meters; there is no reason to suspect that the two MRM's differ with respect to repeatability.

The Replication Error

Figure 3.5 shows the upper confidence limit of the replication error (E) for the D-10 and D-21 Mays Meters. The E for D-10 does not show an increasing trend as the E for D-21 increases. Thus, there is no indication that the different Mays Meters are consistently less repeatable on some road sections than on others.

TABLE 3.3. THE SI VALUES FROM THE THREE DEVICES

Section Number	SI_p	SI_m(D-21)	SI_m(D-10)
41	2.45	2.44	2.57
34	2.90	3.15	3.14
33	2.95	3.24	3.17
13	3.10	2.14	2.40
8	3.15	3.54	3.75
6	3.30	2.73	2.60
21	3.50	3.75	3.71
15	3.65	3.08	3.31
28	3.85	3.98	4.10
7	4.45	4.61	4.59

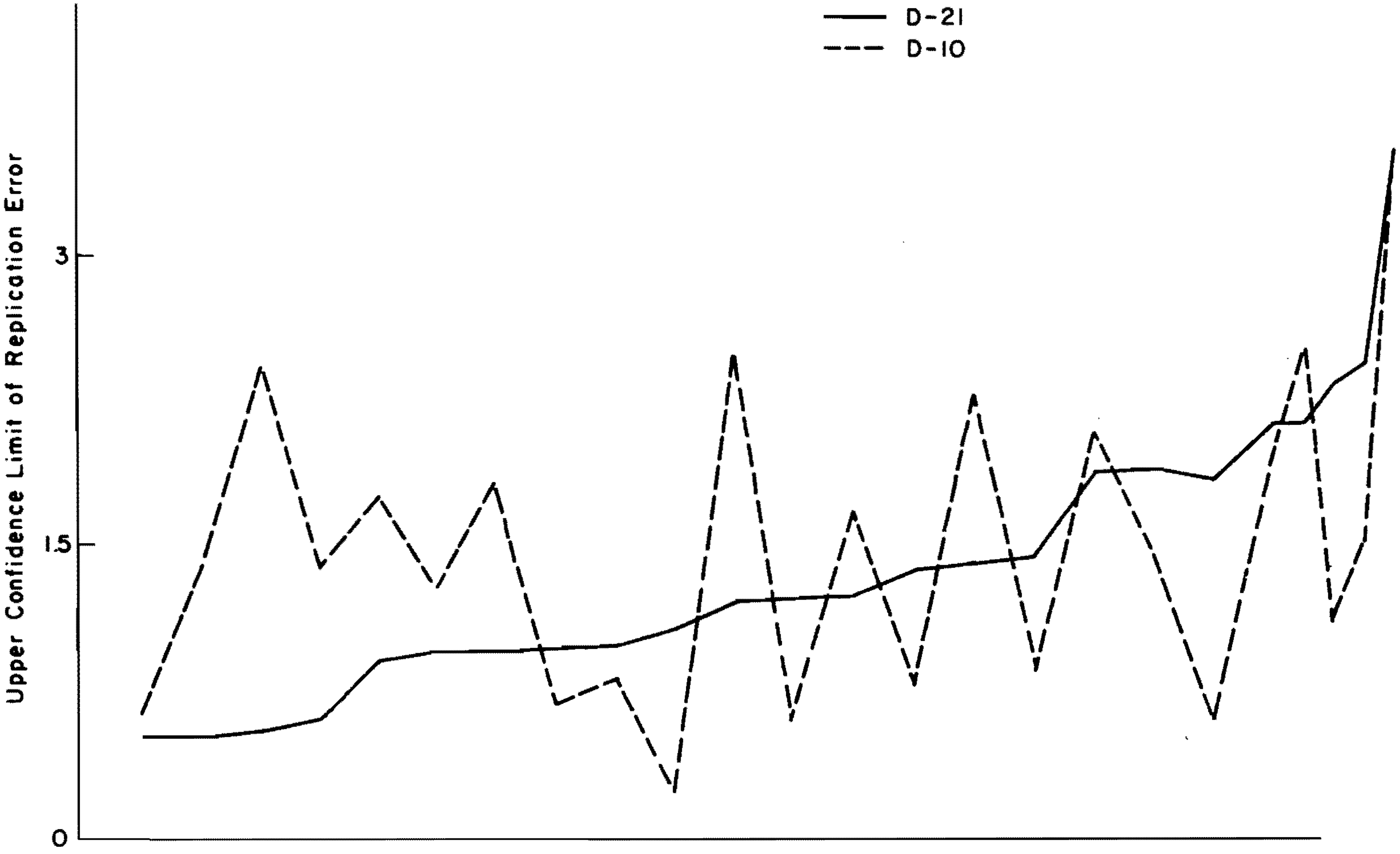
TABLE 3.4. F-TEST FOR THE POOLED REPLICATION VARIANCES FROM THE TWO MRM'S

Mays Meter	Pooled Variance	d.f.	F
D-21	0.011388	78	$1.138 < 1.47$
D-10	0.010011	72	

"d.f." = "degrees of freedom"

SI_p = overall serviceability index for the pavement section obtained from profilometer

SI_m = overall serviceability index for the pavement section obtained from Mays Meter



Section data are plotted from left to right in the order of increasing error for the D-21 MRM

Fig 3.5. The corresponding E value for the two MRM's.

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CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

The Mays Road Meter is a highly dependable measuring device. This statement is based on the following two observations:

(1) The SI values computed from replicate roughness measurements have very small variation. The standard deviation of the SI is a measure of the SI variations and is larger than the SI measurement error about two-thirds of the time. The standard deviations computed for two different Mays Meters and for roads of different qualities are generally 0.1 or less (Table 3.4).

(2) The SI values obtained for the same road sections by making measurements on different dates with different Mays Meters agree to a high extent. Of the SI values for ten sections tested with two Mays Meters, the maximum SI difference is .23. A larger experiment to investigate this point in more detail would be desirable.

The SI values for the same road section computed from MRM and SDP roughness measurements sometimes disagree by over a point. The differences are explainable, however, by the fact that the Mays Meter is sensitive primarily to short waves, while the profilometer SI is based on roughness with wavelengths up to about 86 feet. In view of the two observations above and the fact that the differences can be explained, this point does not indicate the Mays Meter SI is not valid. The Mays Meter SI should probably be considered an excellent summarizing measure of short-wavelength roughness only. A study has been done on the subjective response and the roughness waves (Ref 3). It indicates the riding quality of the road section is probably most dependent on waves about eight feet in length. Thus, being able to respond to short waves very accurately, the MRM is capable of measuring the most important roughness present on the road.

It was suspected that the MRM measurement variation would be greater on rougher roads; this is because the inevitable small variation in the wheelpaths followed in replicate runs causes more variation in the measured roughness if the road surface is irregular. If such a difference exists, however, it is not discernible from the small sample of road sections used in this study.

The piecewise linear models set up in Chapter 2 are crude, but very useful; the models can be used to transform roughness amplitudes into other characterizing roughness measures which are much more easily interpreted from the standpoint of riding quality.

The above observations are in no way intended to imply that the MRM eliminates the need for a more expensive instrument such as the SDP. Due to the effect of the suspension system on MRM measurements, periodic recalibration of an MRM as its springs and shock absorbers age is required if the measurements are to have a consistent meaning. A time-stable device such as the SDP is needed in order to provide data for these calibrations (see Ref 1). The SDP, moreover, provides a much more detailed roughness characterization than does the MRM. The more sophisticated measurements are required for some studies of pavement properties, such as the ones discussed in Refs 2 and 3.

RECOMMENDATIONS

The suspension system will react differently to the roughness of the road as the speed of the vehicle changes. Within certain limits, the Mays Meter responds to long waves more for a vehicle travelling fast than one travelling slow. This idea can be illustrated by Figure 4.1.

It is recommended that a study be done combining the responses of the Mays Meter runs at the speed of 20 mph and 50 mph.

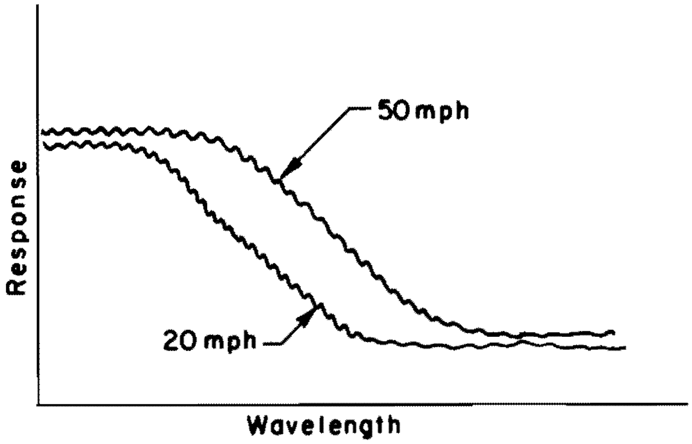

Fig 4.1. Conceptual illustration of Mays Meter responses at different speeds.

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1. Walker, Roger S., and W. Ronald Hudson, "A Correlation Study of the Mays Road Meter with the Surface Dynamics Profilometer," Center for Highway Research, Research Report 156-1, The University of Texas at Austin, February 1973.

2. Walker, Roger S., and W. Ronald Hudson, "The Use of Spectral Estimates for Pavement Characterization," Center for Highway Research, Research Report 156-2, The University of Texas at Austin, August 1973.

3. Holbrook, L. F., and J. R. Darlington, "Analytical Problems Encountered in the Correlation of Subjective Response and Pavement Power Spectral Density Function," Highway Research Board Report No. 471, 1973.

4. Shaw, Chris William, Influence of Testing Variables of the Mays Ride Meter, Master's Thesis, Texas A&M University, December, 1972.

APPENDIX 1

THE PIECEWISE LINEAR MODEL FOR EACH FREQUENCY BAND

APPENDIX 1. THE PIECEWISE LINEAR MODEL FOR EACH FREQUENCY BAND

The piecewise model is set up according to the following conditions:

(1) SI = 5.0 when power equals zero,

(2) SI = 4.25 or SI = 2.25 when the power is equal to the appropriate value listed according to the wavelength in Table A1.1, and

(3) the segment between the above two points is extended and the intersection point on the pwer axis is called P_o . If the power value from any of the sample sections is larger than P_o , P_o is adjusted to be the largest power value so that there will be no negative interpolated SI.

The model is set up by joining these four points. The piecewise linear models are displayed in Figs A1.1 through A1.10.

TABLE A1.1. POINTS USED IN THE PIECEWISE LINEAR MODELS

Wavelength (feet)	Frequency (cycles per foot)	Power	
		PSI = 4.25	PSI = 2.25
86.5*	0.012	1.2945	2.6602*
43.2	0.023	0.0520	0.2538
28.8	0.035	0.0159	0.0759
21.6	0.046	0.0076	0.0307
17.3	0.058	0.0044	0.0249
14.4	0.069	0.0028	0.0174
12.4	0.081	0.0025	0.0108
10.8	0.092	0.0022	0.0087
9.61	0.104	0.0018	0.0082
8.65	0.116	0.0017	0.0084

*See Appendix 5

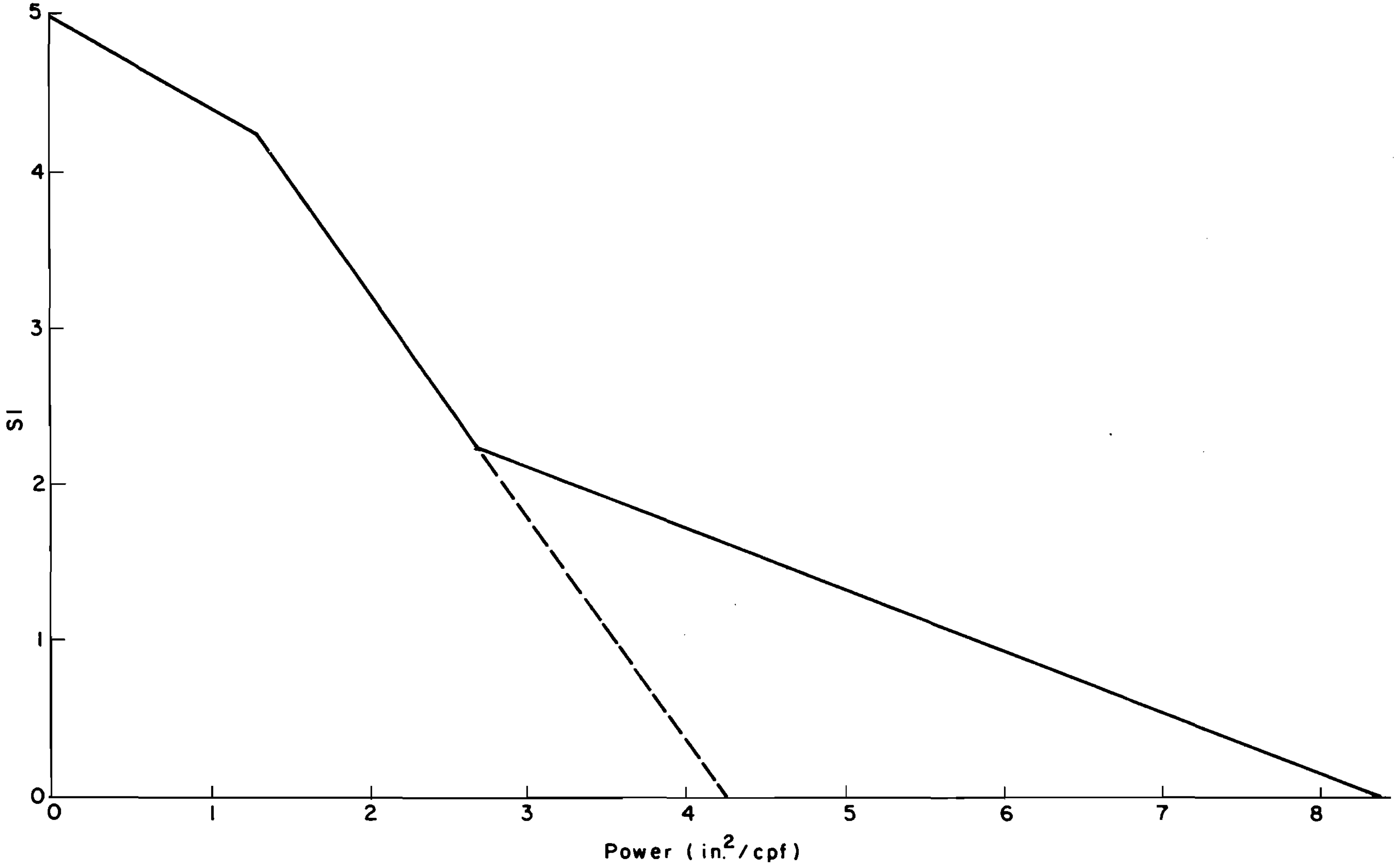

Fig A1.1. Piecewise linear model for wavelength 86.5 feet (frequency 0.012 cpf).

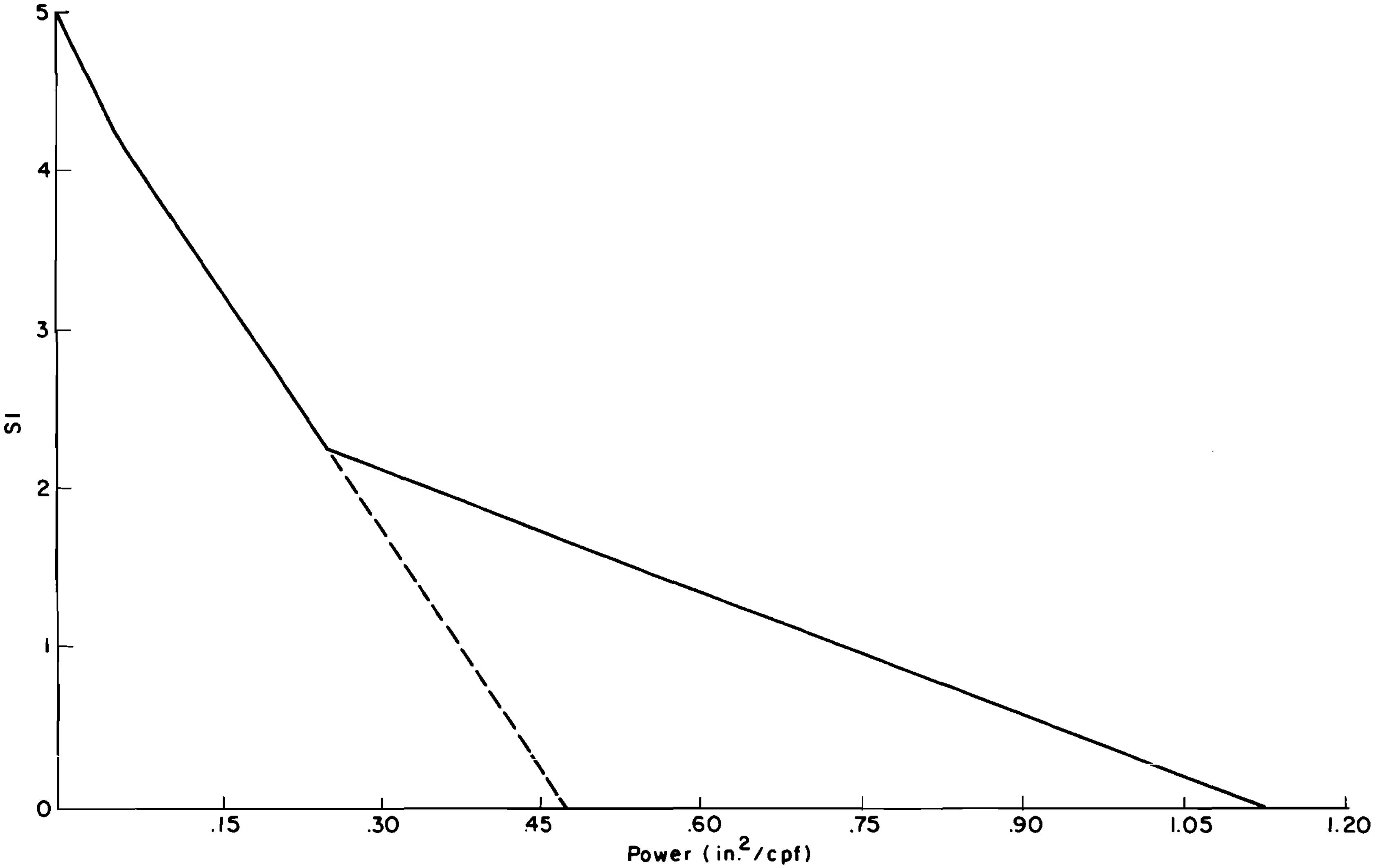

Fig A1.2. Piecewise linear model for wavelength 43.2 feet (freqnency 0.023 cpf).

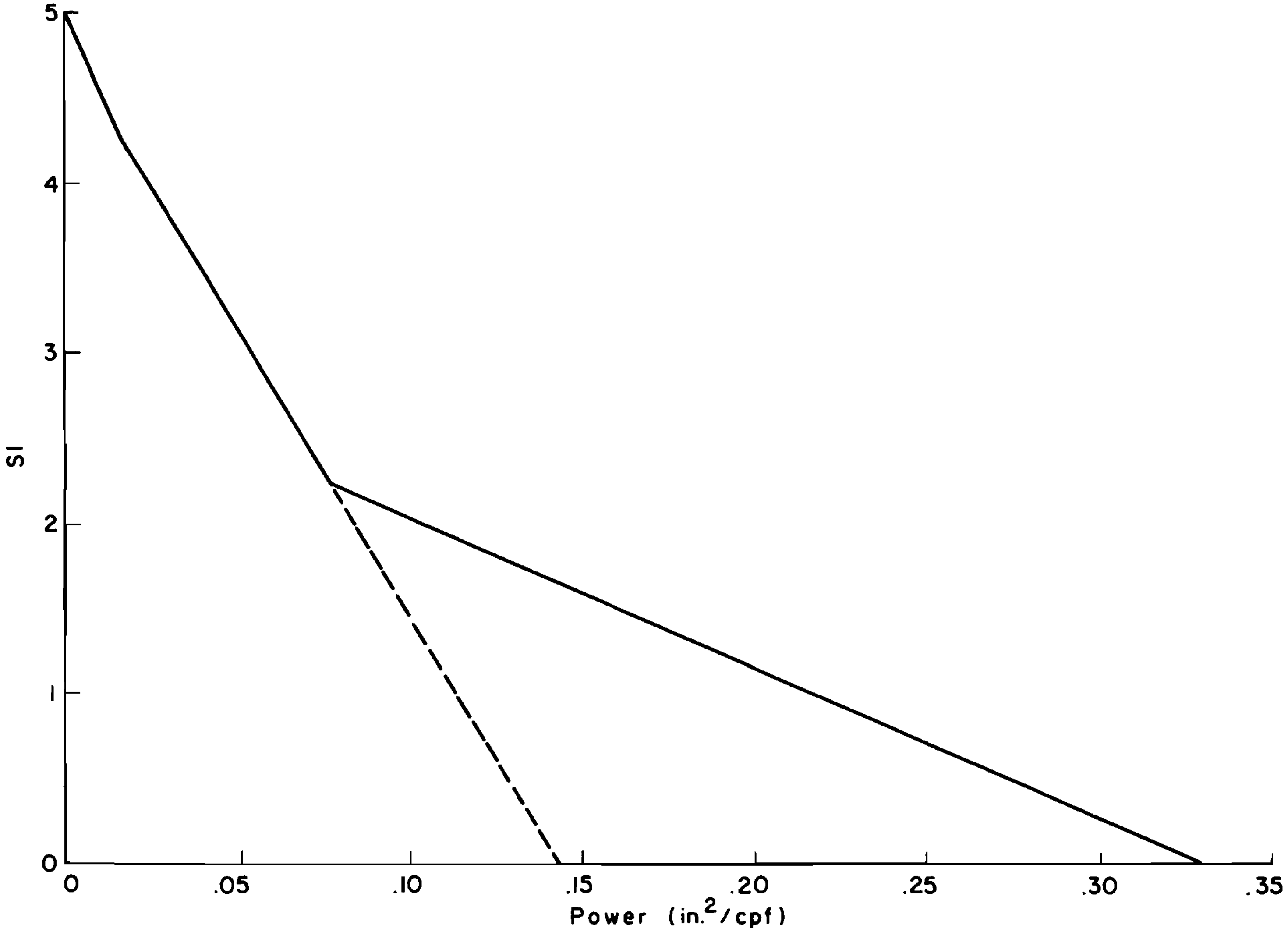

Fig A1.3. Piecewise linear model for wavelength 28.8 feet (frequency 0.035 cpf).

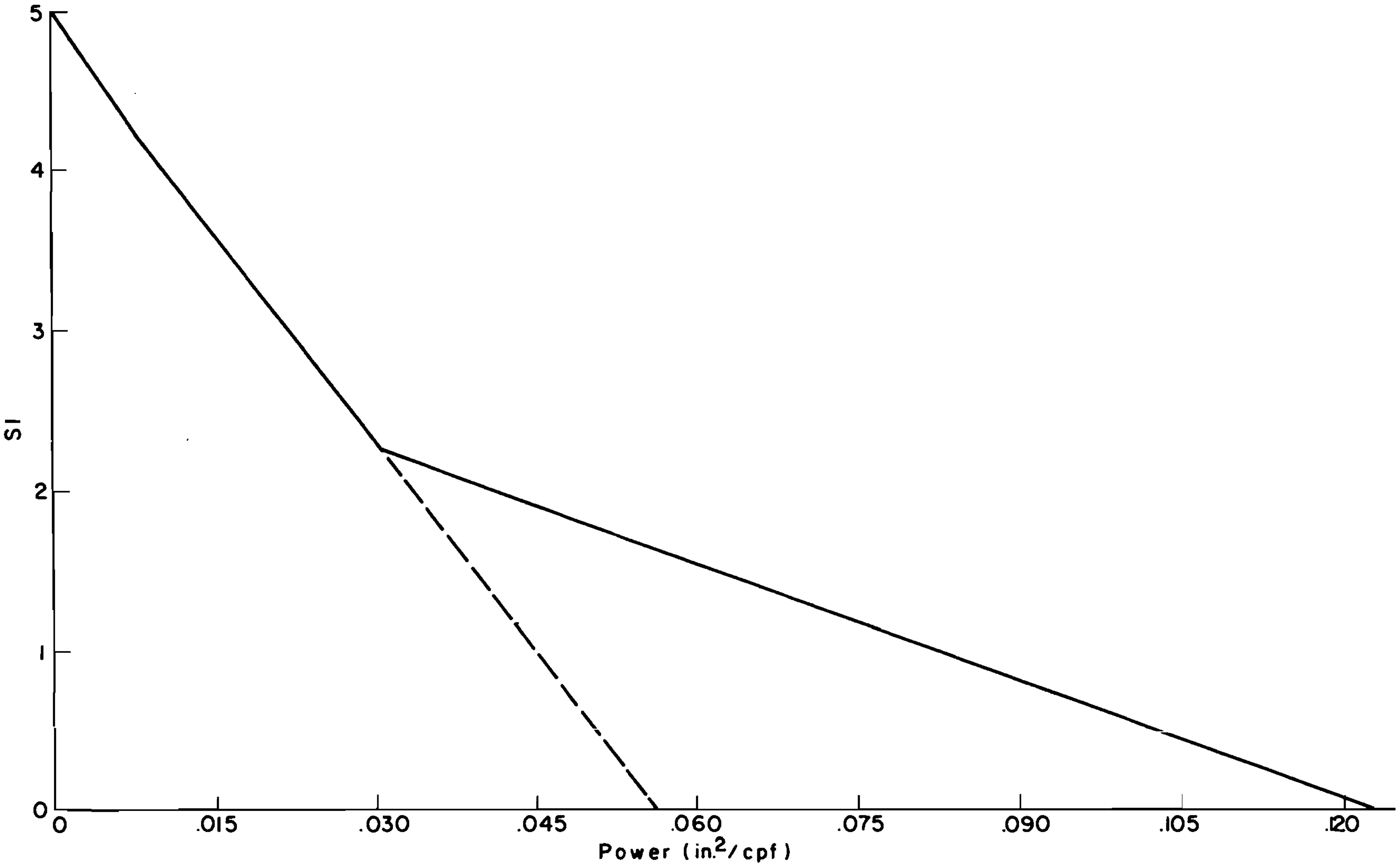

Fig A1.4. Piecewise linear model for wavelength 21.6 feet (frequency 0.046 cpf).

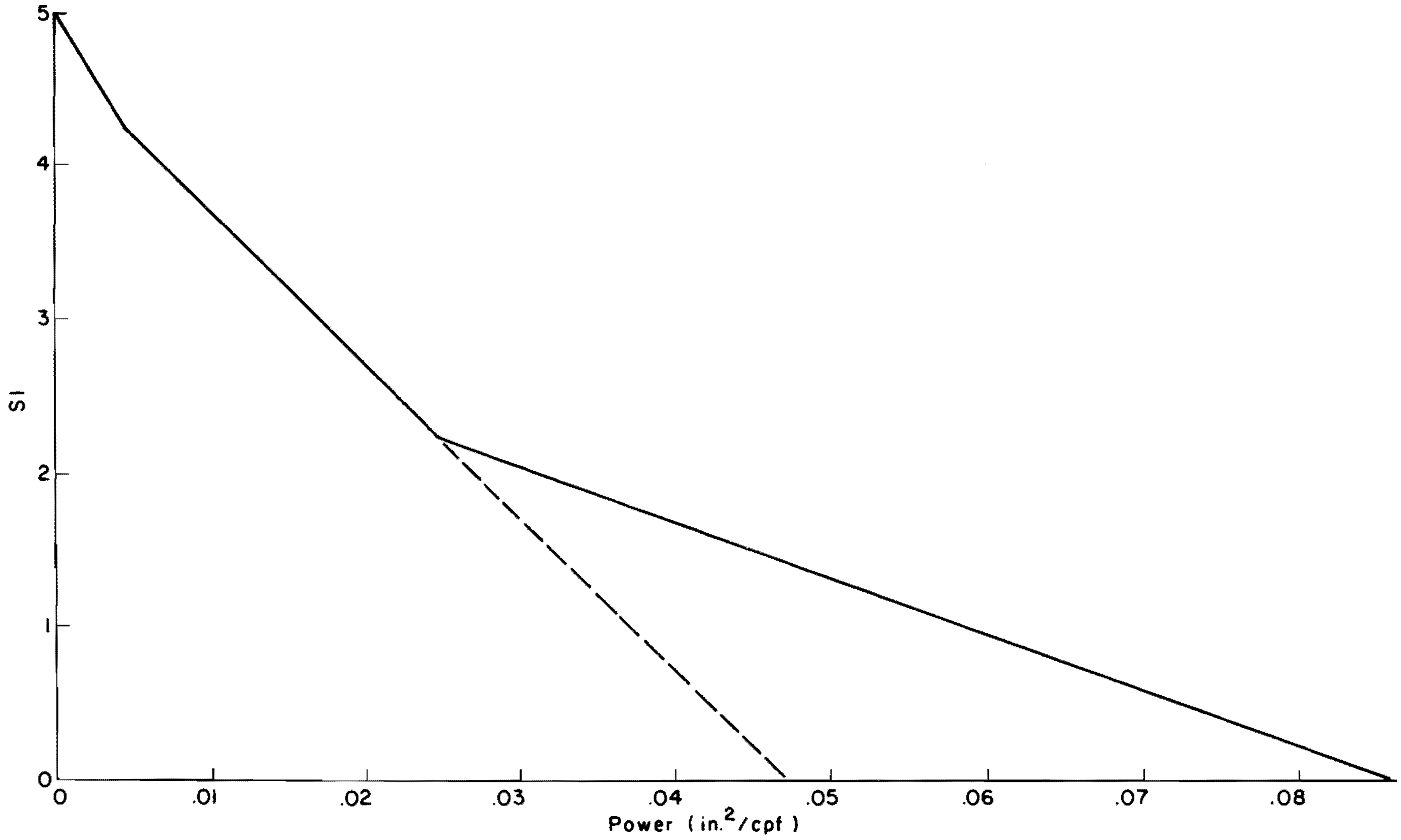

Fig A1.5. Piecewise linear model for wavelength 17.3 feet (frequency 0.058 cpf).

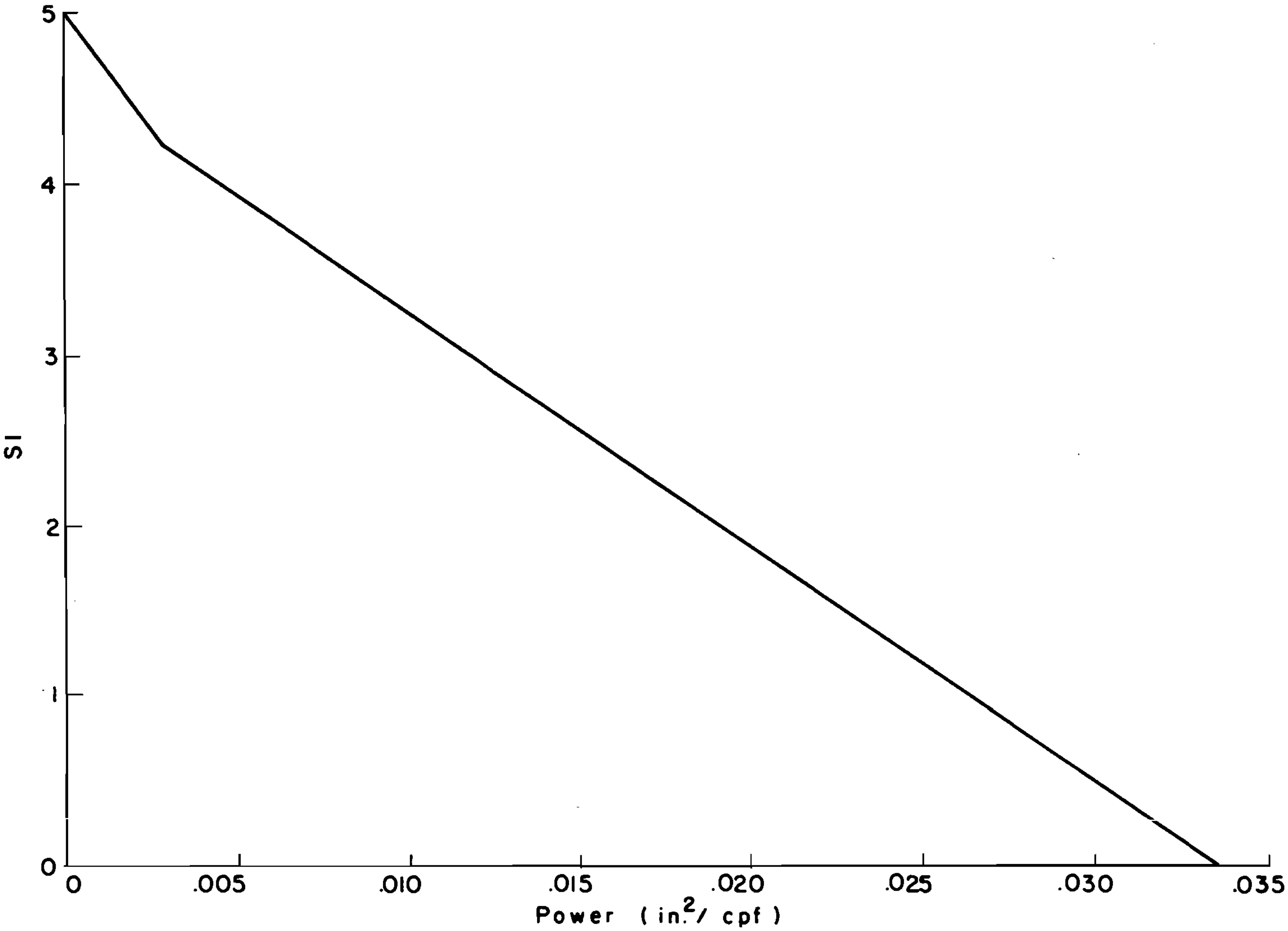

Fig A1.6. Piecewise linear model for wavelength 14.4 feet (frequency 0.069 cpf).

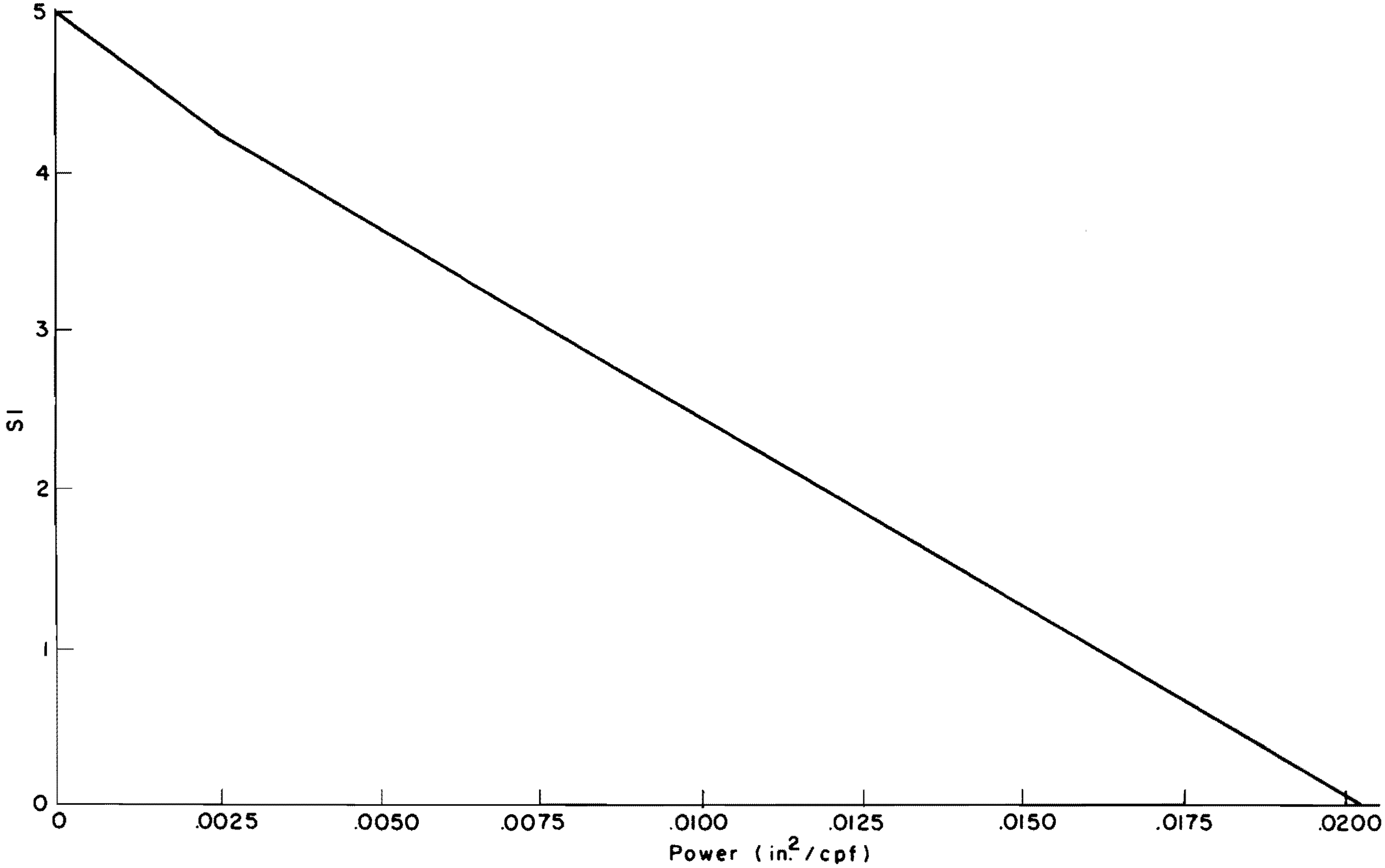

Fig A1.7. Piecewise linear model for wavelength 12.4 feet (frequency 0.081 cpf).

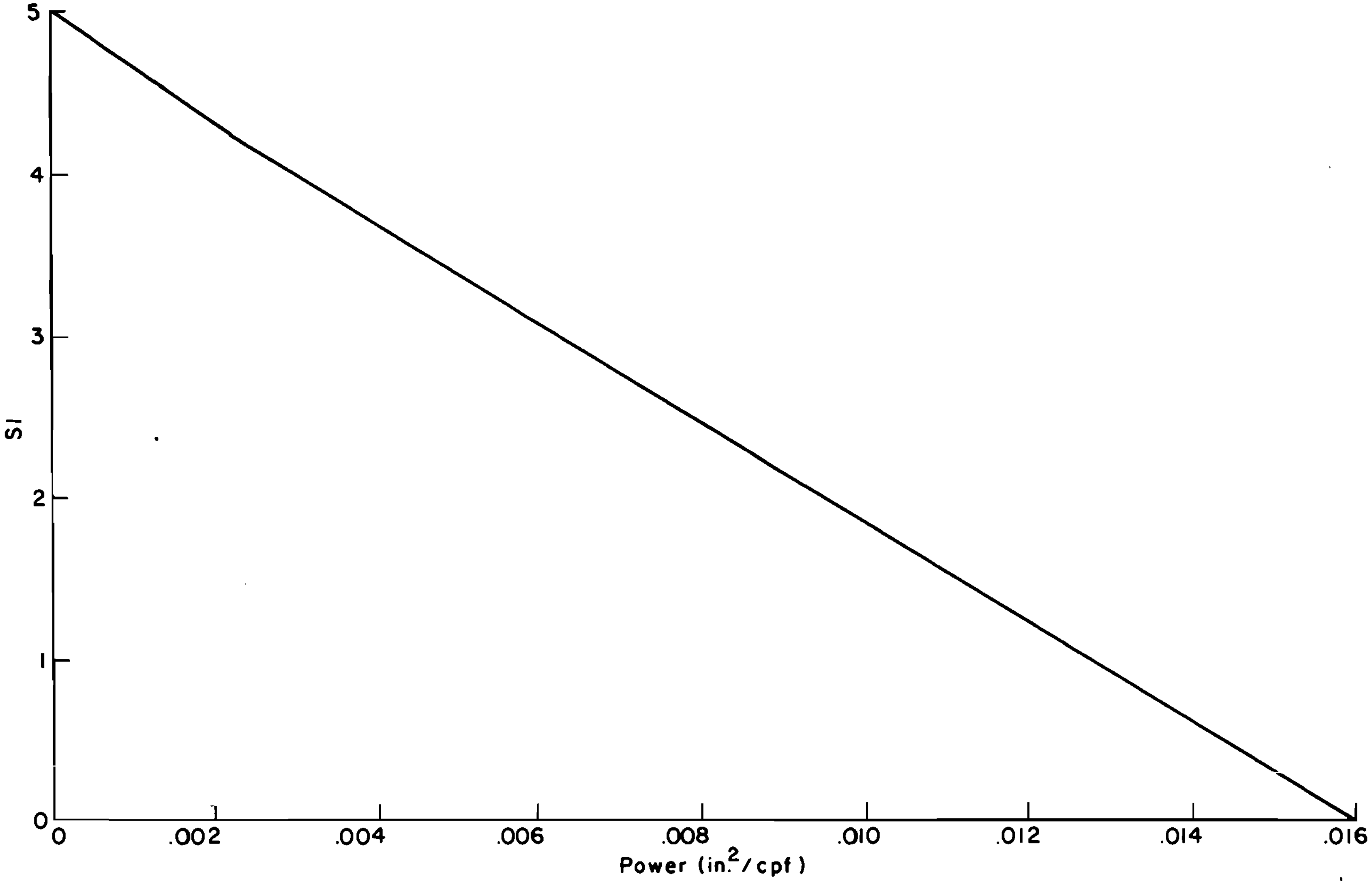

Fig A1.8. Piecesise linear model for wavelength 10.8 feet (frequency 0.092 cpf).

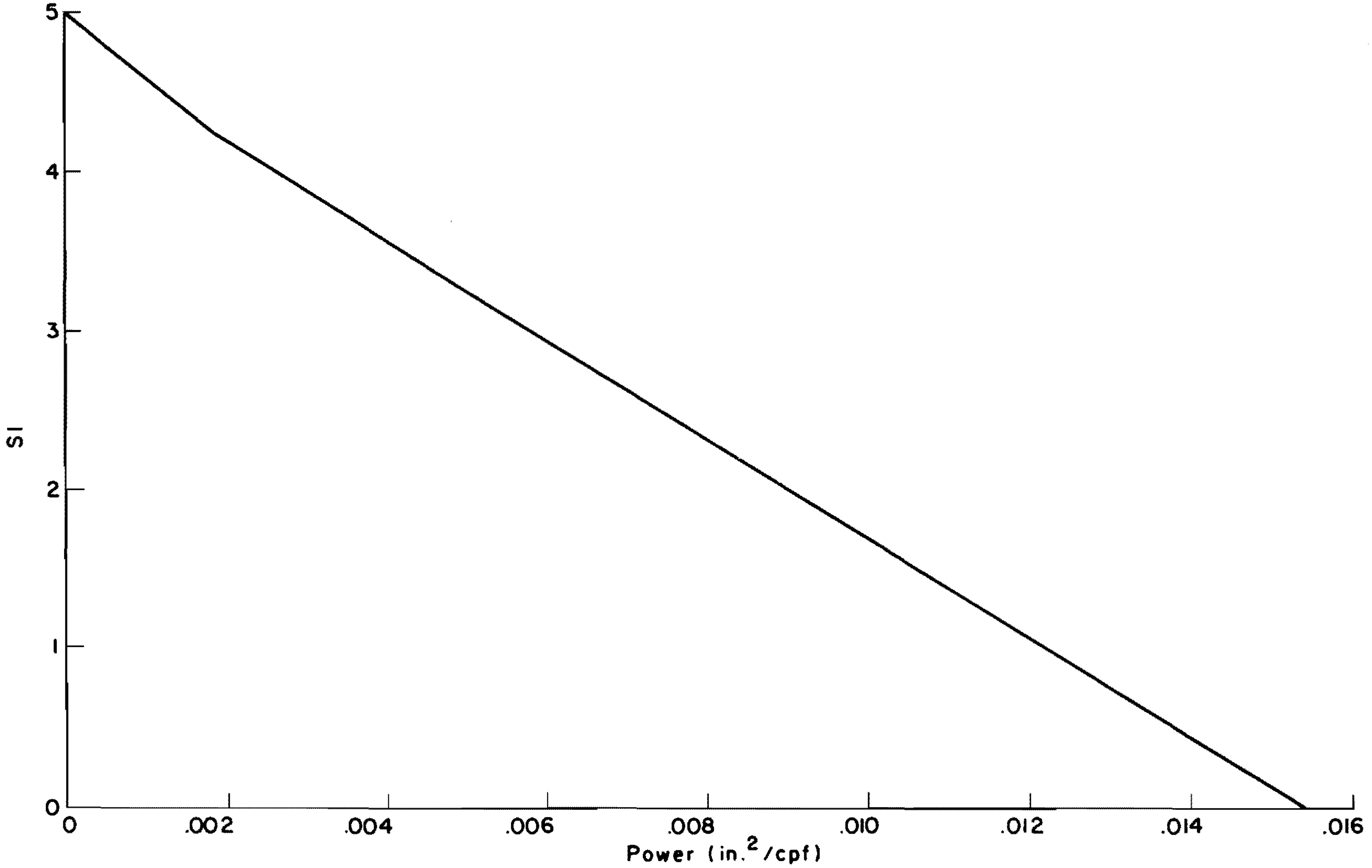

Fig A1.9. Piecewise linear model for wavelength 9.61 feet (frequency 0.104 cpf).

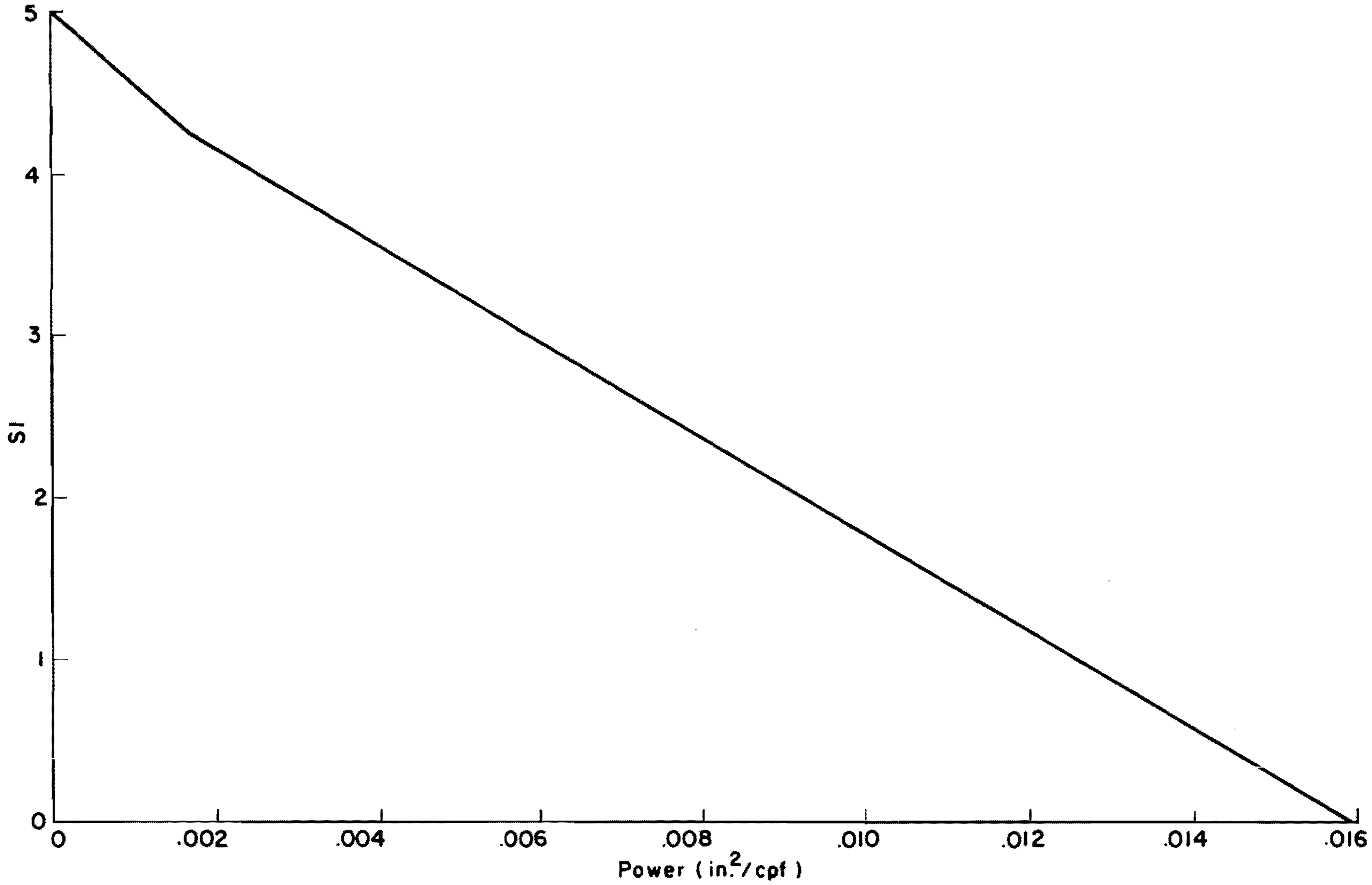

Fig A1.10. Piecewise linear model for wavelength 8.65 feet (frequency 0.116 cpf).

APPENDIX 2

THE CALIBRATION TABLES FOR THE SI_m

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APPENDIX 2. THE CALIBRATION TABLES FOR THE SI_m

Tables A2.1 and A2.2 show the Mays Meter values and the corresponding SI_m values for the D-21 and the D-10 Mays Meters, respectively. These calibration curves for the Mays Meters are based on MRM runs made on October 22, 1974 and November 21, 1974, respectively.

The conversion of MRM roughness measurements to SI values through a calibration procedure employing the SDP is discussed in detail in Ref 1.

TABLE A2.1. TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION OCTOBER 22, 1974 DISTRICT/FILE D-21 MRM NO. 21-142-F

Mays Meter Reading (In/0.2 Mi)	Serviceability Index	Mays Meter Reading (In/0.2 Mi)	Serviceability Index
14.6	0.5	4.6	2.8
13.5	0.6	4.4	2.9
12.6	0.7	4.2	3.0
11.9	0.8	4.0	3.1
11.2	0.9	3.8	3.2
10.6	1.0	3.6	3.3
10.0	1.1	3.4	3.4
9.5	1.2	3.3	3.5
9.1	1.3	3.1	3.6
8.7	1.4	2.9	3.7
8.3	1.5	2.7	3.8
7.9	1.6	2.6	3.9
7.5	1.7	2.4	4.0
7.2	1.8	2.2	4.1
6.9	1.9	2.0	4.2
6.6	2.0	1.9	4.3
6.3	2.1	1.7	4.4
6.1	2.2	1.5	4.5
5.8	2.3	1.3	4.6
5.5	2.4	1.1	4.7
5.3	2.5	0.9	4.8
5.1	2.6	0.6	4.9
4.8	2.7	0.1	5.0

TABLE A2.2. TEXAS HIGHWAY DEPARTMENT - MAYS RIDE METER CALIBRATION NOVEMBER 21, 1974 DISTRICT/FILE D-10 MRM NO. 29-141-C

Mays Meter Reading (In/0.2 Mi)	Serviceability Index_m	Mays Meter Reading (In/0.2 Mi)	Serviceability Index_m
13.8	0.5	4.5	2.8
12.8	0.6	4.3	2.9
12.0	0.7	4.1	3.0
11.3	0.8	3.9	3.1
10.7	0.9	3.7	3.2
10.1	1.0	3.6	3.3
9.6	1.1	3.4	3.4
9.1	1.2	3.2	3.5
8.7	1.3	3.0	3.6
8.3	1.4	2.9	3.7
7.9	1.5	2.7	3.8
7.6	1.6	2.5	3.9
7.3	1.7	2.4	4.0
7.0	1.8	2.2	4.1
6.7	1.9	2.0	4.2
6.4	2.0	1.8	4.3
6.1	2.1	1.7	4.4
5.9	2.2	1.5	4.5
5.6	2.3	1.3	4.6
5.4	2.4	1.1	4.7
5.2	2.5	0.9	4.8
4.9	2.6	0.7	4.9
4.7	2.7	0.1	5.0

APPENDIX 3

STATISTICS ON THE REPLICATION ERROR

APPENDIX 3. STATISTICS ON THE REPLICATION ERROR

There are four repeated MRM runs on each road section. The variance of the repeated runs can be calculated by the following equation:

$$S^2 = \frac{\sum_{i=1}^{n} (Y_i - \overline{Y})^2}{n - 1} \tag{3.1}$$

where

n = number of repeated runs for each section = 4 ,
Y_i = SI_m for the i^{th} individual run, and
$\overline{Y}$ = mean of Y_i .

The variance for each section can be found in Column (5) in Table A3.1 and A3.2.

To obtain the 95 percent upper confidence limit E for the magnitude of the error, we use the t statistic equal to

$$t = \frac{\overline{x} - \mu}{\sqrt{S^2/n}} \tag{3.2}$$

where

$\overline{x}$ = mean of the sample,
μ = the mean of the population, and
S^2/n = variance of the mean.

The upper confidence limit is based on the following derivation

TABLE A3.1. REPLICATION ERROR FOR D-21 MRM NO. 21-142-F ON AUSTIN TEST SECTIONS OCTOBER 22, 1974

Section Number	SI_p	Mays Meter Reading	SI_m	Variance	Standard Deviation	Replication Error α = 5 percent
11	4.1	1.76	4.37	0.003025	0.028	0.091
		1.68	4.41			
		1.76	4.37			
		1.92	4.28			
12	2.3	4.72	2.74	0.001067	0.016	0.052
		4.80	2.70			
		4.72	2.74			
		4.64	2.78			
32	3.5	2.72	3.79	0.007900	0.044	0.142
		3.04	3.63			
		2.88	3.71			
		3.12	3.59			
33	2.9	3.76	3.22	0.005733	0.038	0.121
		3.84	3.18			
		3.84	3.18			
		3.52	3.34			
34	2.9	4.08	3.06	0.013867	0.059	0.188
		4.16	3.02			
		3.68	3.26			
		3.76	3.22			
10	4.0	1.28	4.61	0.003667	0.030	0.097
		1.44	4.53			
		1.36	4.57			
		1.60	4.45			
13	3.1	6.08	2.21	0.014067	0.060	0.190
		6.16	2.17			
		6.72	1.96			
		5.92	2.26			
14	3.3	2.32	4.04	0.001467	0.019	0.060
		2.32	4.04			
		2.24	4.08			
		2.16	4.12			
15	3.6	3.44	3.38	0.049467	0.111	0.353
		4.24	2.98			
		4.08	3.06			
		4.48	2.86			

(Continued)

TABLE A3.1. (Continued)

Section Number	SI_p	Mays Meter Reading	SI_m	Variance	Standard Deviation	Replication Error α = 5 percent
37	3.3	4.72	2.74	0.023158	0.076	0.242
		5.60	2.37			
		5.20	2.55			
		5.12	2.59			
35	1.8	6.16	2.17	0.006000	0.039	0.122
		5.76	2.35			
		6.00	2.23			
		5.84	2.29			
38	2.3	7.68	1.66	0.003567	0.030	0.096
		8.08	1.56			
		7.84	1.62			
		7.52	1.70			
39	1.6	6.08	2.11	0.025533	0.080	0.254
		6.40	2.00			
		6.00	2.15			
		5.44	2.38			
40	3.8	2.72	3.79	0.003025	0.027	0.088
		2.64	3.83			
		2.64	3.83			
		2.48	3.92			
9	4.5	1.68	4.41	0.013758	0.058	0.186
		2.00	4.20			
		2.08	4.16			
		1.76	4.34			
41	2.4	4.80	2.65	0.002700	0.026	0.082
		4.80	2.65			
		5.12	2.53			
		5.28	2.47			
19	3.7	2.88	3.71	0.003200	0.028	0.089
		2.64	3.83			
		2.64	3.83			
		2.72	3.79			
8	3.1	2.80	3.75	0.006692	0.041	0.130
		2.96	3.64			
		2.64	3.83			
		2.72	3.79			
5	3.9	2.32	4.04	0.008292	0.046	0.145
		2.40	4.00			
		2.56	3.87			
		2.24	4.08			

(Continued)

TABLE A3.1. (Continued)

Section Number	SI_p	Mays Meter Reading	SI_m	Variance	Standard Deviation	Replication Error α = 5 percent
3	3.3	3.04	3.58	0.001600	0.020	0.064
		3.20	3.50			
		3.04	3.58			
		3.04	3.58			
6	3.3	4.48	2.81	0.023233	0.076	0.242
		5.20	2.50			
		4.72	2.69			
		5.20	2.50			
2	3.6	6.80	1.87	0.024292	0.078	0.248
		7.52	1.63			
		6.40	2.00			
		6.72	1.89			
7	4.5	1.28	4.61	0.000225	0.008	0.024
		1.36	4.58			
		1.36	4.58			
		1.36	4.58			
23	4.3	1.60	4.45	0.021025	0.072	0.230
		2.08	4.16			
		1.60	4.45			
		1.60	4.45			
1	3.3	3.28	3.46	0.011447	0.054	0.170
		3.44	3.38			
		2.96	3.64			
		3.28	3.46			
21	3.5	2.72	3.79	0.004800	0.034	0.110
		2.72	3.79			
		2.96	3.67			
		2.96	3.67			
28	3.9	2.16	4.12	0.001467	0.019	0.060
		2.24	4.08			
		2.24	4.08			
		2.08	4.16			

SI_p = overall serviceability index for the pavement section obtained from profilometer

SI_m = overall serviceability index for the pavement section obtained from Mays Meter

TABLE A3.2. REPLICATION ERROR FOR D-10 MRM NO. 29-141-C ON AUSTIN TEST SECTIONS NOVEMBER 21, 1974

Section Number	SI_p	Mays Meter Reading	SI_m	Variance	Standard Deviation	Replication Error α = 5 percent
11	4.4	1.44	4.53	0.01209	0.055	0.175
		1.52	4.49			
		1.60	4.45			
		1.84	4.28			
12	3.2	4.56	2.77	0.007500	0.044	0.138
		4.40	2.85			
		4.48	2.81			
		4.80	2.65			
33	3.0	4.16	2.97	0.025100	0.079	0.252
		3.84	3.13			
		3.60	3.30			
		3.60	3.30			
34	2.9	3.60	3.30	0.017092	0.066	0.208
		4.08	3.01			
		4.00	3.05			
		3.76	3.17			
10	4.4	1.60	4.45	0.002100	0.023	0.073
		1.52	4.49			
		1.36	4.57			
		1.36	4.57			
15	3.7	4.00	3.05	0.049225	0.111	0.353
		3.44	3.38			
		3.68	3.26			
		3.04	3.58			
14	3.5	2.16	4.12	0.003600	0.030	0.096
		2.24	4.08			
		2.00	4.20			
		2.00	4.20			
13	3.1	5.20	2.50	0.007867	0.044	0.142
		5.44	2.38			
		5.28	2.46			
		5.60	2.30			
37	3.5	5.28	2.46	0.009100	0.047	0.151
		4.72	2.69			
		4.88	2.61			
		4.96	2.58			

(Continued)

TABLE A3.2. (Continued)

Section Number	SI_p	Mays Meter Reading	SI_m	Variance	Standard Deviation	Replication Error α = 5 percent
36	4.4	1.44	4.52	0.007558	0.044	0.138
		1.20	4.65			
		1.20	4.65			
		1.04	4.73			
35	2.2	5.44	2.38	0.001467	0.019	0.060
		5.36	2.42			
		5.36	2.42			
		5.52	2.34			
38	2.1	6.48	1.97	0.013492	0.058	0.184
		7.12	1.76			
		6.80	1.87			
		7.28	1.71			
39	1.8	6.56	2.01	0.017700	0.066	0.212
		6.56	2.01			
		7.28	1.77			
		6.40	2.07			
40	3.6	2.72	3.79	0.003758	0.030	0.097
		2.64	3.86			
		2.88	3.71			
		2.72	3.79			
9	4.0	1.84	4.33	0.017690	0.066	0.212
		2.24	4.08			
		1.84	4.33			
		1.76	4.37			
41	2.5	5.28	2.51	0.007425	0.043	0.137
		5.52	2.39			
		5.08	2.34			
		5.28	2.51			
19	3.5	2.96	3.67	0.008533	0.046	0.146
		2.96	3.67			
		3.28	3.51			
		3.28	3.51			
8	3.2	3.20	3.55	0.003600	0.030	0.096
		2.96	3.67			
		3.20	3.55			
		3.20	3.55			

(Continued)

TABLE A3.2. (Continued)

Section Number	SI_p	Mays Meter Reading	SI_m	Variance	Standard Deviation	Replication Error α = 5 percent
3	3.0	3.28	3.51	0.001067	0.016	0.052
		3.20	3.55			
		3.12	3.59			
		3.20	3.55			
6	3.3	4.72	2.74	0.001158	0.017	0.056
		4.80	2.70			
		4.88	2.67			
		4.72	2.74			
7	4.4	1.12	4.68	0.004567	0.034	0.108
		1.28	4.64			
		1.36	4.57			
		1.44	4.53			
23	3.9	1.76	4.37	0.007867	0.044	0.142
		1.84	4.33			
		1.44	4.53			
		1.60	4.45			
1	3.0	3.36	3.44	0.006467	0.044	0.127
		3.52	3.34			
		3.28	3.51			
		3.28	3.51			
21	3.5	2.80	3.75	0.021625	0.074	0.234
		3.04	3.63			
		2.96	3.67			
		2.48	3.96			
28	3.8	2.08	4.16	0.015833	0.063	0.204
		2.48	3.96			
		2.48	3.96			
		2.64	3.86			

SI_p = overall serviceability index for the pavement section obtained from profilometer

SI_m = overall serviceability index for the pavement section obtained from Mays Meter

$$\Pr\left\{-t_{\alpha/2} < t < t_{\alpha/2}\right\} = 1 - \alpha \tag{3.3}$$

$$\Pr\left\{-t_{\alpha/2} < \frac{\bar{x} - \mu}{\sqrt{S^2/n}} < t_{\alpha/2}\right\} = 1 - \alpha \tag{3.4}$$

$$\Pr\left\{\mu - t_{\alpha/2}\sqrt{S^2/n} < \bar{x} < \mu + t_{\alpha/2}\sqrt{S^2/n}\right\} = 1 - \alpha \tag{3.5}$$

The E values shown in column (7) in Tables A3.1 and A3.2 are equal to $t_{0.025}\sqrt{S^2/n}$. Figures A3.2 and A3.3 show the E values for each section measured by the D-21 and the D-10 MRM, respectively. The items in the columns are as follows:

Column (1) = section number,

Column (2) = SI_p of the section on the specific date given,

Column (3) = MRM roughness readings from the four repeated runs,

Column (4) = the SI_m's obtained by interpolating the value in Column (3) into Tables A2.1 and A2.2. Tables A2.1 and A2.2 correspond to Tables A3.1 and A3.2, respectively,

Column (5) = replication variance obtained from Eq. 3.1,

Column (6) = standard deviation of the mean; this standard deviation is equal to (variance/number of repeated runs)$^{1/2}$, and

Column (7) = E value obtained by multiplying the value in Column (6) by the $t_{0.025}$ value.

APPENDIX 4

ANALYSIS OF VARIANCE

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APPENDIX 4. ANALYSIS OF VARIANCE

To test the hypothesis of equal replication variances for the sections with high and low SI, the F statistic is calculated:

$$F = \frac{\displaystyle\sum_{i=1}^{L} \frac{S_i^{(1)^2}(N_i^{(1)}-1)}{\sigma_1^2} \Bigg/ \left[\sum_{i=1}^{L}(N_i^{(1)}-1)\right]}{\displaystyle\sum_{i=1}^{M} \frac{S_i^{(2)^2}(N_i^{(2)}-1)}{\sigma_2^2} \Bigg/ \left[\sum_{i=1}^{M}(N_i^{(2)}-1)\right]} \qquad (A4.1)$$

where

L = number of sections with low SI_p's (2.5 and below),

M = number of sections with high SI_p's (4.0 and above),

N_i = number of repeated runs for the i^{th} section,

S_i^2 = as defined in Eq. A3.1 in Appendix 3, and

σ_1^2, σ_2^2 = the replication variances of the sections with low and high SI_p's respectively.

The superscripts (1) and (2) refer, respectively, to the cases of (1) low and (2) high SI values. The hypothesis tested is

$$H_o: \sigma_1^2 = \sigma_2^2 .$$

Since N_i is equal to 4 for all the sections, the formula can be simplified, under H_o, to be

$$F = \frac{\sum_{i=1}^{L} S_i^{(1)^2} \Big/ L}{\sum_{i=1}^{M} S_i^{(2)^2} \Big/ M}$$

Thus,

$$\sum_{i=1}^{L} S_i^{(1)^2} \Big/ L$$

and

$$\sum_{i=1}^{M} S_i^{(2)^2} \Big/ M$$

are pooled variances of the sections with low and high SI_p , with 3L and 3M degrees of freedom, respectively.

By comparing the F value calculated and the $F_{v_1, v_2, 0.95}$ value, the significance of difference of variance can be judged.

APPENDIX 5

THE EFFECT OF CERTAIN ERRORS ON THE RESULTS

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APPENDIX 5. THE EFFECT OF CERTAIN ERRORS ON THE RESULTS

It has been found that there are mistakes in Fig A5.1 and Table 2.1, which were developed in Ref 2. The values in the table are not consistent with the plot.

From Table A5.1 and Fig A5.1, it can be seen that the table values are approximately ten times as great as the plot values, except for the 86.5 foot wavelength case. The computer drawn curves are evidently correct, but the vertical scale which was later added is apparently off by a factor of ten. That the error is in the plot and not the table is suspected because of the reasonable interpolated SI values obtained in this study by using the table power values and because of the reasons discussed below.

For the wavelengths of 43.2 feet or shorter, we can see that the power mean values for the PSR interval of 2.0 to 2.5 are nearly four times as great as those for the interval of 4.0 to 4.5.

The tabulated power values for wavelength 86.5-feet, however, are inconsistent with the general trend. Additionally, it can be seen from Fig A5.1 that if plotted, the tabulated value of 2.6606 would give the curve for PSR = 2.0 - 2.5 a shape entirely different from all the other curves. For these reasons, the power value of 4.8 (including the factor of 10), not the tabulated value of 2.6606, is probably correct. It is not alarming that this value has only one effective digit after the desired point. A 0.1 difference in the power value will not change the plot much and the interpolated SI obtained from this plot is only used for comparison.

Due to this change, some of the interpolated SI values and the observed results will change. The corrected SI values are given in Table A5.2.

Since the only power mean value that needs correction is the one for 86.5-foot waves, the interpolated SI values for the short waves are unaffected by the correction. Therefore, the same results are observed for the short waves, while those concerning the long waves will change minutely. The results are summarized below.

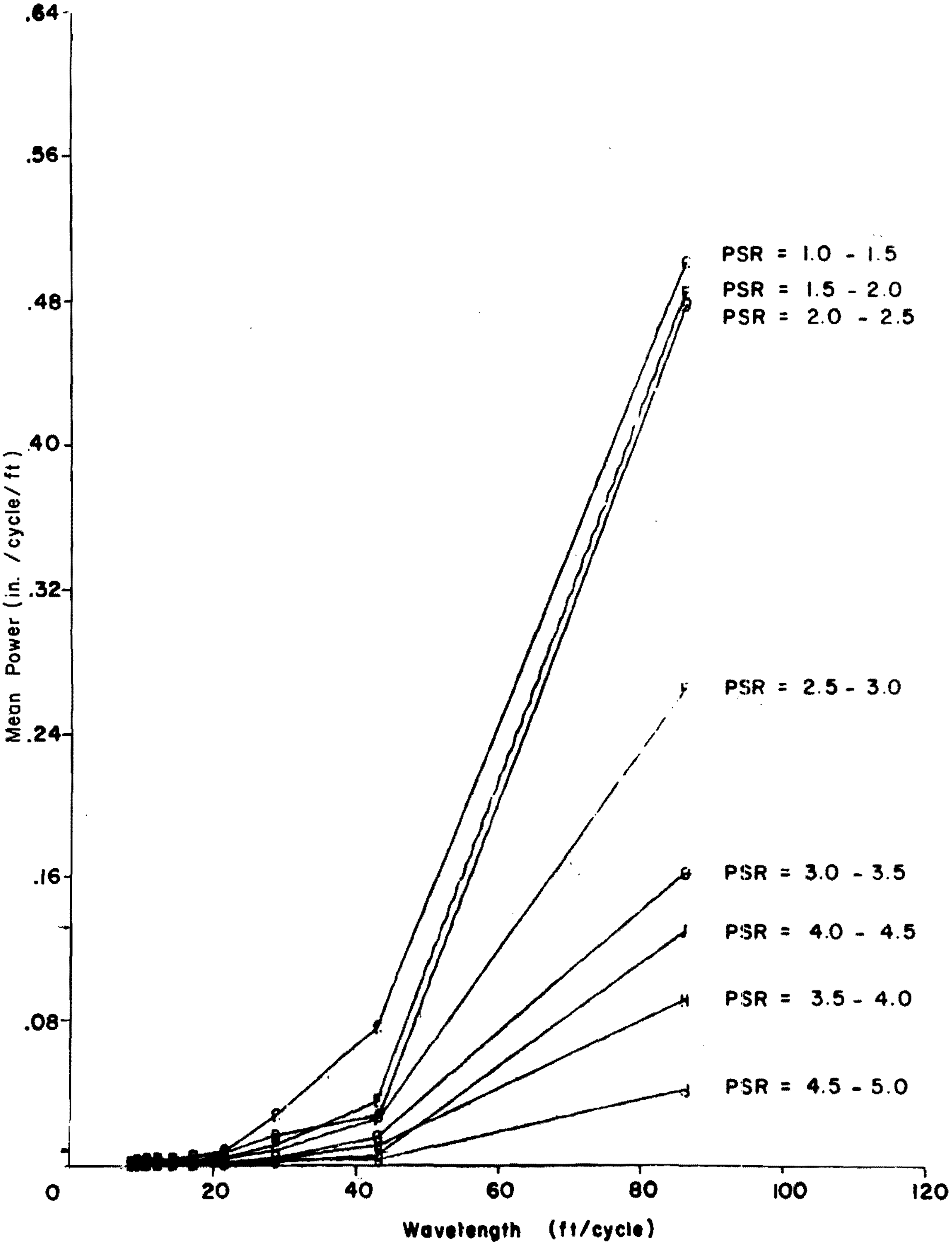

Fig A5.1. Wavelength versus power spectral estimates (64-band) for rating session data.

TABLE A5.1. COMPARISON OF THE POWER MEAN VALUES FOR ROADS WITH SERVICEABILITY RATINGS OF (1) 2.0 TO 2.5 AND (2) 4.0 TO 4.5.

		Power Mean (in^2/cpf)		
		PSR Interval		
Wavelength (feet)	Frequency (cpf)	2.0 - 2.5	4.0 - 4.5	Ratio of the Power Means
86.5	0.012	2.6606	1.2945	2.06
		4.8		3.71
43.2	0.023	0.2538	0.0520	4.88
28.8	0.035	0.0759	0.0159	4.77
21.6	0.046	0.0307	0.0076	4.04
17.3	0.058	0.0249	0.0044	5.66
14.4	0.069	0.0174	0.0028	6.21
12.4	0.081	0.0108	0.0025	4.32
10.8	0.092	0.0087	0.0022	3.95
9.61	0.104	0.0082	0.0018	4.56
8.65	0.110	0.0084	0.0017	4.94

TABLE A5.2. CORRECTION OF TABLE 2.2. INTERPOLATED SI FOR EACH FREQUENCY BAND FOR THE HUNTSVILLE CRCP SECTIONS FEBRUARY 1974

		$SI_p < SI_m$ (Type d)				$SI_p > SI_m$ (Type b)				
	SI_p	2.5	3.1	3.1	3.2	4.1	4.5	4.6	4.7	5.0
	SI_m	3.5	3.4	3.4	3.3	3.3	3.2	3.2	3.3	3.2
Wavelength (feet)	Frequency (cpf)									
86.5	0.012	1.5	3.1	4.4	1.8	4.3	4.1	4.8	4.8	4.8
43.2	0.023	3.3	0.0	3.2	2.3	3.6	3.5	4.2	4.0	4.1
28.8	0.035	1.6	1.6	2.6	1.9	4.0	3.4	3.6	3.7	4.3
21.6	0.046	2.7	2.0	1.8	2.1	3.6	4.4	4.0	3.8	4.2
17.3	0.058	2.0	0.0	3.0	3.0	3.8	4.3	4.1	3.6	3.9
14.4	0.069	2.6	1.3	3.8	3.2	4.0	4.4	4.1	3.6	4.1
12.4	0.081	3.1	2.0	4.0	3.4	4.4	4.4	3.9	3.0	4.2
10.8	0.092	2.2	4.2	3.8	3.5	4.6	3.9	4.1	3.8	4.6
9.61	0.104	3.3	3.7	4.1	3.9	4.5	4.2	4.2	3.8	4.1
8.65	0.116	3.7	2.9	4.1	4.2	4.5	4.1	4.3	4.1	4.7

SI_p = overall serviceability index for the pavement section obtained from profilometer

SI_m = overall serviceability index for the pavement section obtained from Mays Meter

For the Huntsville sections. From Table A5.2, we can see that the sections with the low SI have generally lower interpolated SI values for long wavelengths than for short wavelengths. This is substantiated by the following observations:

(1) For the two shortest wavelengths, 8.65 and 9.61 feet, the lowest SI value is 2.9 and the other seven SI are 3.3 or above. For the five wavelengths of 14.4 feet or shorter, only three of the 20 SI values are less than 2.5.

(2) For the five larger wavelengths, from 17.3 to 86.5 feet, each road section has an SI value below 2.0 and 12 (instead of 13) of the 20 SI values are less than 2.5.

For the Austin Test Sections. Table A5.3 shows that

(1) the short waves are weighted more heavily in SI_m than in SI_p. Notice that the interpolated SI values for the short waves are systematically lower if $SI_p > SI_m$ (left of the table) than if $SI_p < SI_m$ (right of the table). For the five wavelengths of 14.4 feet or shorter, all the SI on the right are 4.2 or above, and eight of 25 are greater than or equal to 4.5. While all the corresponding SI on the left are less than 4.2 and eleven out 20 are lower than 4.0.

(2) The SI_p values for all the sections studied vary within a small range. Thus, we might expect the SI values for the long waves would be lower on the right to offset the higher SI values for the short waves. Similar to what was observed from Table 3.1, this does not seem to be true. This, again, is attributed to the complex composition of the roughness amplitude of the SI_p.

From the analysis above, we can see that the conclusions remain the same even though an error was found in one of the power mean values.

The corrected piecewise linear model for the 86.5-foot wavelengths is shown in Fig A5.2.

TABLE A5.3. CORRECTION OF TABLE 3.1. INTERPOLATED SI FOR EACH FREQUENCY BAND FOR THE AUSTIN FLEXIBLE TEST SECTIONS NOVEMBER 1974

		$SI_p > SI_m$ (Type b)				$SI_p < SI_m$ (Type c)				
	SI_p	3.50	3.30	3.10	3.20	3.30	3.50	3.30	3.50	3.10
	SI_m	2.59	2.60	2.40	2.78	3.48	3.71	3.57	4.15	3.75
	$SI_p - SI_m$	0.91	0.70	0.70	0.42	-0.18	-0.21	-0.27	-0.65	-0.65
Wavelength (feet)	Frequency (cpf)									
86.5	0.012	3.8	2.5	3.8	2.0	2.0	4.0	1.9	3.7	4.5
43.2	0.023	4.2	3.1	3.7	3.9	3.7	4.2	3.4	4.2	3.7
28.8	0.035	3.7	3.5	3.4	4.1	4.2	4.2	3.0	4.1	2.7
21.6	0.046	3.0	3.8	3.2	4.3	4.2	4.5	3.4	4.3	2.8
17.3	0.058	4.1	4.2	4.1	4.2	4.4	4.3	4.4	4.6	4.4
14.4	0.069	4.0	4.0	3.6	4.1	4.2	4.2	4.2	4.2	4.5
12.4	0.081	4.1	4.1	3.5	3.8	4.2	4.3	4.2	4.6	4.4
10.8	0.092	3.6	4.1	3.6	3.3	4.4	4.3	4.2	4.2	4.5
9.61	0.104	3.9	4.1	3.6	3.7	4.4	4.3	4.2	4.3	4.5
8.65	0.116	3.9	4.1	4.0	3.6	4.7	4.6	4.4	4.8	4.6

SI_p = overall serviceability index for the pavement section obtained from profilometer

SI_m = overall serviceability index for the pavement section obtained from Mays Meter

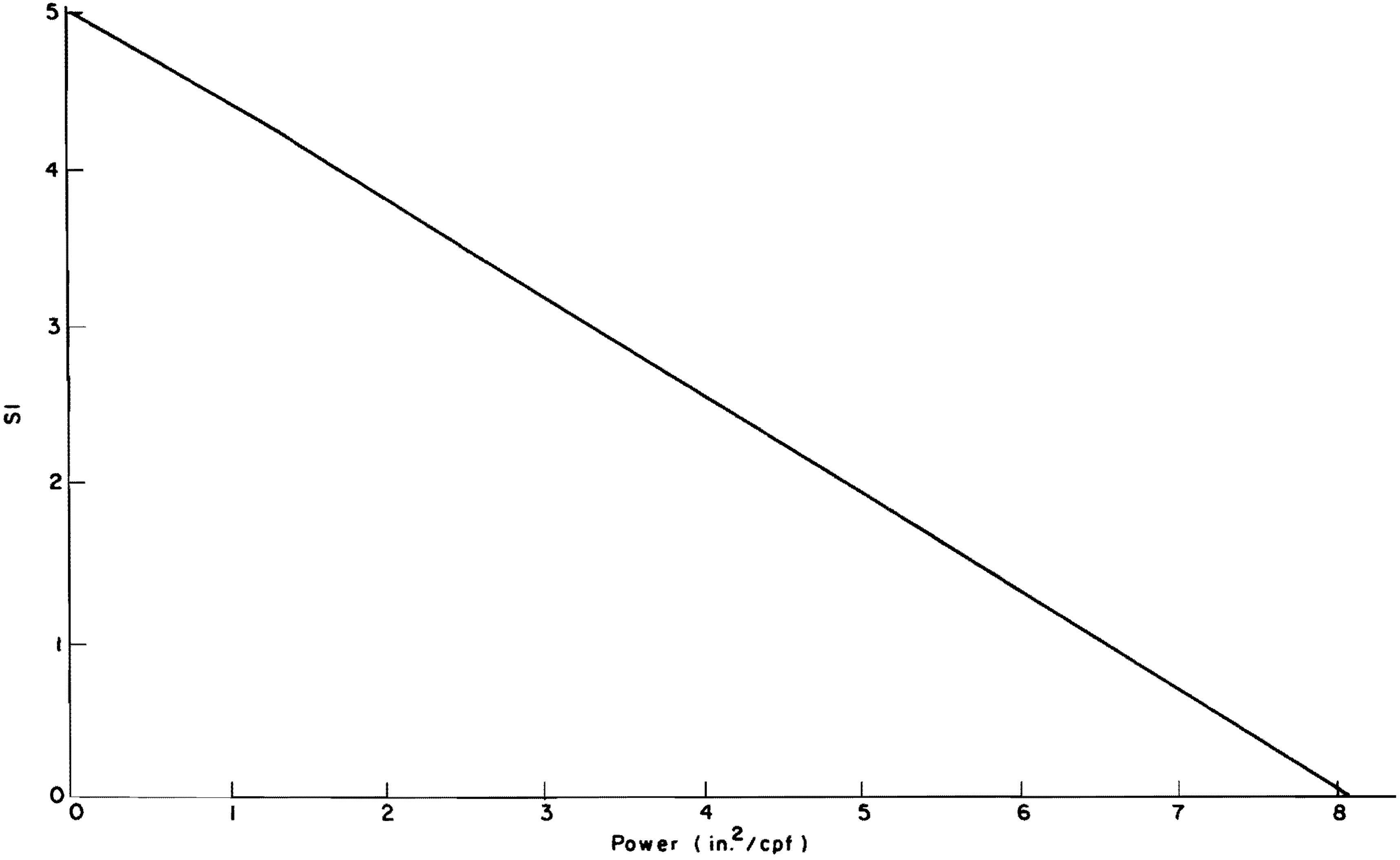

Fig A5.2. The corrected piecewise linear function for 86.5 foot wave.

APPENDIX 6

BRIEF DISCUSSION OF MRM OPERATION

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APPENDIX 6. BRIEF DISCUSSION OF MRM OPERATION

The operation of MRM's in Texas, including principally the calibration of MRM's to allow calculation of SI values from MRM roughness values, is treated in detail in Ref 1. Thus, this extensive discussion will not be reproduced here. In this Appendix, however, certain operating conditions which affect the measurements are discussed briefly.

The calibration processs consists of

(1) running the MRM on a set of over 20 standard test sections and obtaining an MRM roughness measurement for each section. Current SI values obtained from the SDP are maintained for these sections.

(2) using statistical methods to obtain a function which can be used to compute the SI value corresponding to any given MRM roughness measurement for the particular MRM being calibrated.

Once these two steps have been completed, the function developed can be used until the suspension system changes sufficiently to affect the measurements to a significant extent. A test for the necessity of recalibration is discussed in Ref 1.

The standard operating speed of the MRM's is 50 miles per hour; all data discussed in this report were obtained by running at this speed. All test sections are one-quarter mile in length. Except for the new MRM trailers, which are not discussed here, the Mays Meter instrumentation is installed in standard-sized American automobiles. Only automobiles with coil springs in front and leaf springs in the back are used.

The drivers who perform the calibration runs are employees of the department or agency which will operate the MRM in practice. Thus, any possibility of errors due to large variations in the weight of the crew can be eliminated by having the calibration runs made by the crew which will operate the instrument between calibrations.

Tire pressures are checked before running, and the car is filled with gas at the beginning of each day during the calibration process. At the end of a day's work, the tank will be about one fourth full, so near constant weight in the gas tank is <u>not</u> maintained during calibration. Mr. Brad Hubbard of the SDHPT has indicated, however, that tests have been performed in which the weight in the car was varied from 200 to 550 pounds; in the latter case, a 180-pound weight was placed on the rear floor board. The resulting MRM measurements varied only about 10 percent, which is comparable to the amount of random run-to-run variation expected in any case. An error of 10 percent in the MRM roughness measurement typically corresponds to an error of .1 to .2 in the SI value computed from the measurement.

Calibrations are not performed under any unusual weather conditions, such as rain or high winds. Five replicate runs are ordinarily made, and the most deviate one is discarded. The four measurements which are kept are averaged to obtain the MRM measurement to be used in the calibration. If any unusual conditions occur on a given run, such as the passage of a heavy truck from the opposite direction causing momentary high wind pressure, the affected run can be discarded if the measurement is out of line with the other replicate MRM values.

Neither the road sections used for calibration nor any other test sections used in this report have any isolated, unusual roughness effects, such as railroad tracks or ends of bridges.

The subject of the effect on MRM measurement of uncontrollable factors, such as wind, and imperfectly controllable factors, such as the weight in the car, is an important concern which is separate from the problems discussed in this report. These effects, however, are discussed in Ref 4. It is stated in the conclusions of that reference that, "When operated and maintained properly, the MRM will provide a uniform and accurate determination of an existing pavement's SI value."

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