Profilograph Correlation Study with Present Serviceability Index

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Several states are beginning to use roughness measurements from the Rainhart and California profilographs for construction control of rigid pavements. Texas is also considering using the profilograph for such purposes. However, the relationship between the roughness measurements provided by these devices and Present Serviceability Index (PSI), as obtained from the Surface Dynamics Profilometer (SDP), is unknown. Since the initial PSI of pavements is currently used in estimating the life of a pavement, the relationship between roughness measurements from the profilograph and PSI is needed. The other two roughness measuring devices used by the state, the Walker Self-Calibrating Roughness Device (WRD) and the Mays Ride Meter (MRM), have been correlated to PSI. A common measure of roughness, the PSI, is needed for all roughness measuring units to maintain consistent measurements. The paper provides correlations between Present Serviceability Index (PSI), as obtained from the Surface Dynamics Profilometer (SDP), and Profile Index (PI) from the California and Rainhart Profilographs. In addition to the correlations with PSI, correlations are also provided between each profilograph with one another and between roughness data from the WRD. A mathematical model of the two profilographs is provided, and the measuring capabilities of the two profilographs to various road profile frequencies or wavelength components is illustrated.

Several states are using roughness measurements from the Rainhart and California profilographs for construction control of rigid pavements. However, the relationship between the roughness measurements provided by these devices and Present Serviceability Index (PSI), computed from profile data obtained with the Surface Dynamics Profilometer (SDP), is unknown. Since the initial PSI of pavements is currently used in estimating the life of a pavement, the relationship between roughness measurements from the profilograph and PSI is needed.

Texas is considering the use of the profilograph for new construction specifications. The SDP has been used by the Texas State Department of Highways and Public Transportation (TSDHPT) for a number of years for obtaining road profile measurements. These measurements are then used for obtaining PSI. The PSI obtained has been found to provide consistent, objective, and reliable results and is currently used in the state as the standard for roughness measurements. Because of the high use and maintenance costs of the SDP, the less expensive Mays Ride Meter (MRM) and, more recently, the Walker Self Calibrating Roughness Measuring Device (WRD) are currently used in the state for large scale roughness measurements. These two devices are correlated to PSI from the SDP to provide a standard roughness measurement statistic. Since the profilographs may become the standard roughness measuring device for accepting or rejecting new or rehabilitated pavements, a study of its measuring capability was needed.

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STUDY PLAN

The initial study plan of the project was to select 20 to 25 rigid pavement sections 0.2 mi long and to measure these devices with the California and Rainhart Profilographs, the SDP, and the WRD. The profile index of the two devices would then be computed using both a 0.1- and 0.2-in blanking band. The PSI of the sections would also be computed for both the SDP and WRD.

Details on the measuring equipment used and the data sections selected are presented. The equipment used is owned by the State Department of Highways and Public Transportation. Forty-one rigid sections were obtained as opposed to the originally planned 20 to 25. These sections were selected from newly constructed and older rigid pavements in the Beaumont, Angleton, and Dallas areas.

Mathematical models of the two profilographs are developed, and the accuracy of the model is determined by comparing the actual profilograph output and the output predicted. The models could be used to investigate the effects of different roughness wavelengths and amplitudes. Also included are the power spectral estimates of the road profile data of these sections, grouped according to PSI.

The Data Analysis section discusses the correlations performed. These correlations include correlations between the two profilographs for the two blanking bands, correlations between the profilographs and PSI, correlations between the profilographs and the WRD, and correlations between the SDP and the WRD.

MEASUREMENT EQUIPMENT AND DATA COLLECTION

Four different roughness measuring devices were used in this research study: the Surface Dynamics Profilometer, the California and Rainhart Profilographs, and the Walker Self-Calibrating Roughness Device (also known as the Slometer). Forty-one rigid pavement sections, each 0.2 mi long, were selected in three different areas of the state. Each device was used on each section to get roughness measurements.

A brief description of the roughness measuring devices is provided in the next four sections. The pavement sections, data collection procedures used, and corresponding roughness measurements are given in the last section.

Surface Dynamics Profilometer

The Surface Dynamics Profilometer was originally designed by General Motors and built by K. J. Law Engineers in 1967. The device has, as primary sensors, two accelerometers and two linear potentiometers. The potentiometers are connected to road-following wheels. The accelerometers determine the amount and direction of vertical acceleration undergone by the vehicle while the potentiometers and wheels measure the distance from the vehicle body to the road surface. A profile measurement is calculated by summing the double integral of the accelerometer signal and the displacement signal from the potentiometer (*3*). Recently, two non-contact, or Selcom laser, probes were installed on the SDP, replacing the potentiometer/road-following wheel combination (*7*).

California Profilograph

The California style profilograph used is a 32-½-foot-long mechanical pavement roughness measuring device with 12 wheels, purchased from McCracken Co. The profilograph can be quickly assembled or diassembled so that it can be easily transported from location to location. When used to collect roughness information, it is pushed by an operator at walking speeds. It records roughness traces through a recording wheel at the center of the device. As the profilograph travels, a tracing pen connected to the recording wheel picks up the upward and downward motions of the wheel. The recorded trace (profilogram) usually has a 1-inch = 25-foot ratio in the horizontal direction and actual variation in the vertical direction.

Rainhart Profilograph

The Rainhart Profilograph operates on a similar principle as the California Profilograph. The major difference between these two devices is in the reference plane on which the recording device is supported. The Rainhart Profilograph also has 12 wheels; however, each wheel travels on a different profile path, whereas the California profilograph travels only on three profile paths (the left right wheels on one path, the right four wheels on another, and the third under the recording wheel). The Rainhart Profilograph, with a length of 26 feet 10 inches, is composed of a major body frame and four rigid tripods, each being a rigid frame and wheels at each apex. These four tripods are then connected to the major body of the profilograph through a ball joint support located on the geometric center of the tripods. The recording wheel travels on the center path of the profilograph and records the vertical movement of the recording wheels relative to the body frame.

The profilogram recorded by Rainhart profilograph is processed in the same manner as the California profilogram in order to obtain the Profile Index (*1*). However, a blanking band of 0.1 inch is typically used for Rainhart profilogram in calculation of PI. A similar ruler with a 0.1-in blanking band can be used to count the scallops and to compute the index.

Although a 0.1-in blanking band is typically used when comparing with the California profilograph, for the research effort both a 0.1- and 0.2-in blanking band were used and compared.

Walker Roughness Device

Even though the profilometer produces accurate measurements, it is rather expensive to obtain and operate. Because of this the Mays Ride Meter and, more recently, the WRD are currently being used in Texas for roughness measurements. The WRD provides an estimate of the road profile. From these measurements various statistics can then be obtained. The WRD currently uses slope variance of the predicted profile, which has been correlated to PSI, to determine the serviceability index (SI) of the road. Consideration is also being given to providing other statistics such as RMSVA or the International Roughness Index Statistic.

The WRD consists of three components: a sensor unit, main control module and, optionally, a computer for storing the results. The device uses an accelerometer as its primary sensor. Before using the device for measurements it is driven over a short road section, which is used by the WRD to perform a statistical model of the vehicle's response. The model parameters determined in this dynamic calibration procedure are later used during the measuring process for removing the vehicle's characteristics. Identifying and modeling the current or dynamic vehicle characteristics are referred to as the self-calibrating process.

The WRD, in general, is a compact device that can be installed and operated in virtually any vehicle. It is simple to use and can be operated by one person. It is inexpensive compared to the SDP and is not much more than the cost of the MRM with trailer.

Data Collection Procedures

Forty-one rigid pavements sections 0.2 mile long were selected for the research. These sections were selected from roads in the Angleton, Beaumont, and Dallas areas of Texas. Each section was run by all four roughness measuring devices. The general geographical section location and name given to each section can be found in Walker and Lin (*7*).

The time and effort required to assemble and dismantle each profilograph, as well as to operate them (such as traffic control, etc.), played a major role in selecting the sections. Additionally, attempts were made to select sections that had various levels of roughness, although more sections were selected for the newer and smoother sections. The larger number of smoother sections were selected, as one of the major interests in the study was to determine the relationship between PSI and profile index for control of newly constructed pavements. Some older and rougher sections were selected, however, so that a broader comparison could be made in correlating the devices with one another and to provide boundary points for the models.

Table 1 provides a matrix of the processed measurement values. The table provides the profile index of each profilo-

TABLE 1 VALUES OF PROCESSED MEASUREMENTS

SECTION NAME	SDP PSI	PROFILOGRAPHS				WRD	
		CALIFORNIA		RAINHART		SV	SI
		BB=0.1	BB=0.2	BB=0.1	BB=0.2		
A1A	2.11	111	93.3	81.07	77.14	2835	2.12
A1B	1.84	70.75	60.75	47.25	26.5		
A2A	4.44	7	3	2.5		176	4.33
A2B	4.22	5	2.25	1.75	0.75	232	4.11
A2C	4.21	10.5	4.25	2.75	0.25	249	4.05
A2D	4.28	10.75	3.75	3.25		245	4.06
A2E	4.32	4.75	2	2.75	0.5	205	4.27
A3A	4.17	10.25	2.25	3.5	0.5	205	4.27
A3B	3.99	12.25	7	5.56	1.4	81	3.89
A3C	4.1	13	4.5	4.25	0.5	192	4.26
A3D	4.22	14.75	9.5	7	1.5	148	4.46
A3E	4.16	11.5	2.75	3.75	0.25	169	4.36
A4A	3.88	15.5	6	6.25	0.5	254	4.04
A4B	4	11.25	5.25	3.25	0.25	227	4.12
B1	2.68	51.5	42.25	45.25	27.75	811	3.11
B2A	2.71	78.5	61.5	53.25	37.8	1601	2.57
B2B	3.11	73	55.5	50.5	34.8		
B2C	2.63	78	63.75	56	40	2433	2.24
B3A	2.9	38.5	26.25	32.5	12.5	934	3
B3B	2.87	44.25	29.75	34.5	9.75	764	3.16
B3C	2.73	39.75	26.5	27.5	13.25	612	3.34
B4	2.16	90.5	72.25	60.25	39.5		
B5	3.49	34.5	23.5	17.75	8	555	3.41
B6A	3.6	31.5	21.25	17	7.75	539	3.44
B6B	3.84	35	24	27	8.25	554	3.42
B7A	3.01	42.25	24.5	17.75	7.5	1006	2.94
B7B	3.03	42.75	28.25	26.25	13.75	757	3.17
B7C	3.16	46.75	30.5	22	7.5	724	3.2
B8A	3.21	30	19.5	15.75	9.5	688	3.24
B8B	3.14	28	17.5	13.25	10.5	453	3.58
B8C	3.22	26	18.75	13.6	5.5	631	3.31
D1A	3.79	19.5	11.5	9.75	2.75	524	3.68
D1B	3.7	22.5	12.25	10.25	2.25	1521	3.6
D1C	3.85	18.75	12	10.5	3.5	1120	3.85
D1D	3.9	21	16	9.75	1.25	651	3.92
D1E	4.02	18.75	9.75	8.75	2	302	4.02
D2A	4.51	10.75	5	3.25	2.5	295	4.37
D2B	4.58	9.25	3.75	1.5	1.25	204	4.5
D2C	4.54	6.25	1.75	1	0.25	180	4.3
D2D	4.15	18.5	9.75	7	3.25	317	3.93
D2E	3.97	17.25	9	6	1.75		3.64

graph for the 0.1- and 0.2-in blanking bands. The profilographs were run only once on each section. The PSI readings from the SDP are the average of two and three readings. The average of three runs was used for the WRD except for the Beaumont sections. For these sections, only one run was made. The slope variance readings from the WRD are unscaled (the WRD provides these values along with SI). Measurements from the WRD were made at 50 mph. Since three of the sections could not be used at this speed only 38 sections were used for the WRD data.

PROFILOGRAPH MODEL DEVELOPMENT

The Rainhart and California profilographs operate mechanically in a very similar fashion to measure pavement roughness. In order to understand better the mechanical behaviors of the profilographs, two mathematical models were built to simulate the operation of the measurements. With the flexibility of these two models, the responses of the models with respect to various profiles can be investigated.

Mathematical Modeling of Profilographs

With the information supplied by manufacturers and physical inspections of the profilographs, two mathematical models have been implemented such that, given an exact road profile, they will produce profilograms as in real measurement from the profilograph device. The following assumptions were adopted during the development of both California and Rainhart profilograph computer models:

- All structural connections are perfect rigid connections. This is true since all connections on the profilograph are reinforced.
- Since hinge joints are designed with bearing on the profilograph, all hinges and pivot joints are assumed to be perfect pin connection structures such that no friction occurs. All wheels are also assumed to have frictionless bearings.
- The profilograph is made of linear elastic material.
- The profilograph starts from a self-equilibrium state in the vertical direction, and it remains in this condition throughout the operation stage.
- The profilograph moves at a slow speed (usually less than 2 mph) such that dynamic effects can be neglected; in other words, the mass (inertia) effect of the profilograph structure is ignored.
- All wheels of the profilograph makes continuous contact with the road. In addition, a point (knife-edge) contact assumption for all wheels is adopted in the computer models. Each wheel can travel on a different profile.

With the above assumptions, the profilograph can be modeled as a skeletal-frame system. Detailed discussions of the development of the profilograph models are given in Walker and Lin (*7*).

Verification of the Mathematical Models

Two mathematical models for the California and Rainhart profilographs were developed in accordance with the assumptions in the preceding section. They are later investigated by comparing their response to profile data measured with the SDP. The actual profilograph traces taken from the same sections are compared to the model's predicted traces. Several recordings have been made using both profilographs. Since it is difficult to get all profiles under each wheel of the profilograph for the model, the same profile measured and computed from the SDP will be used as the real profile for all wheel paths. This assumption can be justified when the sections measured have smooth lateral profiles. Furthermore, the path of the profile recorded by the SDP is carefully aligned with that of the recording wheel of the profilograph, since the profile under this wheel has a direct influence on the results produced by the model.

Figure 1 shows a recording from the California profilograph, SDP measured profile, and the result generated from the mathematical model. The profiles computed from the SDP are also shown in the corresponding figures (the SDP computes two profiles in one run. The right wheel profile from the SDP is the one coinciding with the path of the recording wheel of the profilograph). It should be noted that the profile recorded by the SDP is in digital discrete form such that there are some minor discrepancies compared with the analog recording from the actual profilographs. The results presented are computed using profile from the SDP for sample rates of 2 samples per foot. The Profile Index is also computed for each result using a 0.2-inch blanking band for the California device and 0.1-in for the Rainhart profilograph. The calculation procedures for PI follows specification as described by Georgia Highway Department and by State of California Department of Public Works (*1*, *4*).

Inspection of the results reveals that the mathematical model produces a trace similar to the profilograph recording. The accuracy of the discrete profile fed into the model is the major factor influencing the results. That is, the greater the sample-per-foot resolution of the profile data used, the better the comparison. The better results were found as the sample rate of the profile data was changed from 2 to 10 and 20 samples per foot. Another factor influencing the accuracy is the fact that the models assume a point-contact wheel as compared to rubber wheels used in the actual device. The latter acts as a filter that smooths out some of the micro behavior of what the models predict. The models were used to compute the profile index for all 41 sections and compared to the actual measurements. In general, the results from the computer model are comparable to the real profilograph recordings.

Frequency Response Study Using the Model

In order to understand the behavior of these two models, a profile of unit-amplitude sine function for all wheel paths is fed into the models, and the simulated recordings are generated. That is, the function $P(x) = \sin(2\pi x/\lambda)$ is used for each wheel, where λ is the wave length or period of the sine function.

Figure 2 shows the simulated recordings from two profilograph models for unit amplitude sine function profiles with a wave period equal to 390 inches. Figure 3 shows the same results but with a sine function of shorter wave period, or 195 inches. It is noted that the maximum amplitude produced depends on the period of the input sine function. In Figure 2, the California model produces a higher peak amplitude than the Rainhart profilograph model. However, the situation

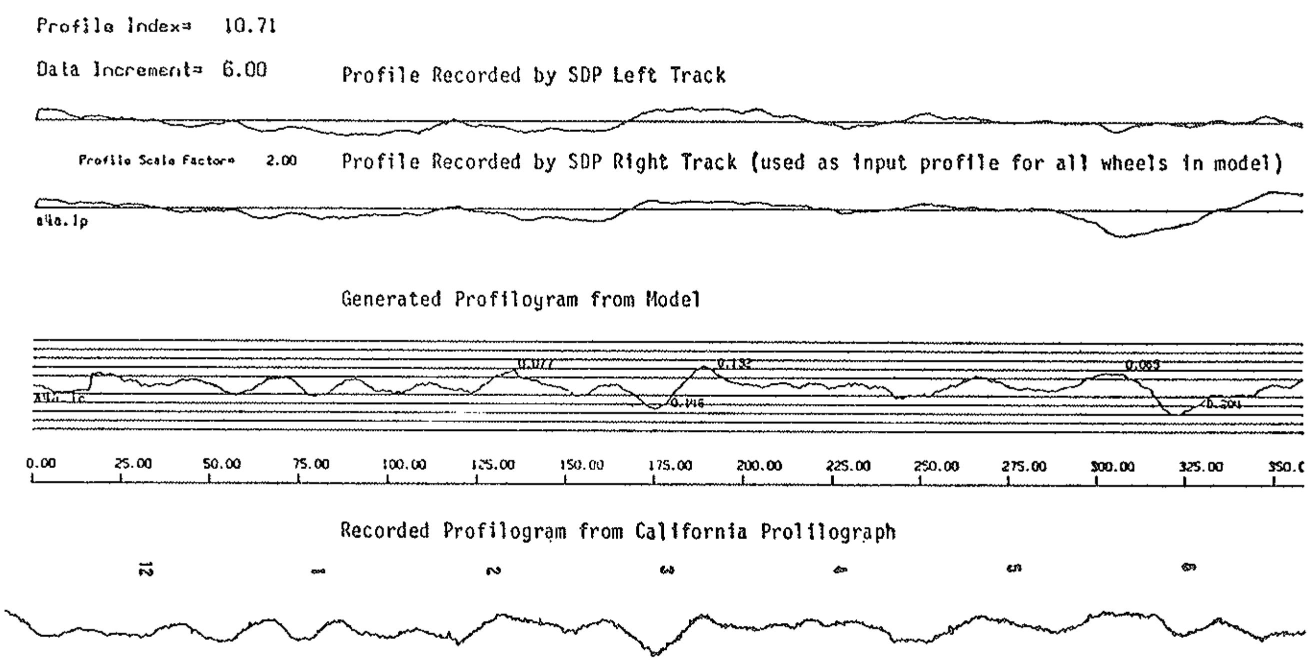

FIGURE 1 Computed and recorded profilograms for California profilograph.

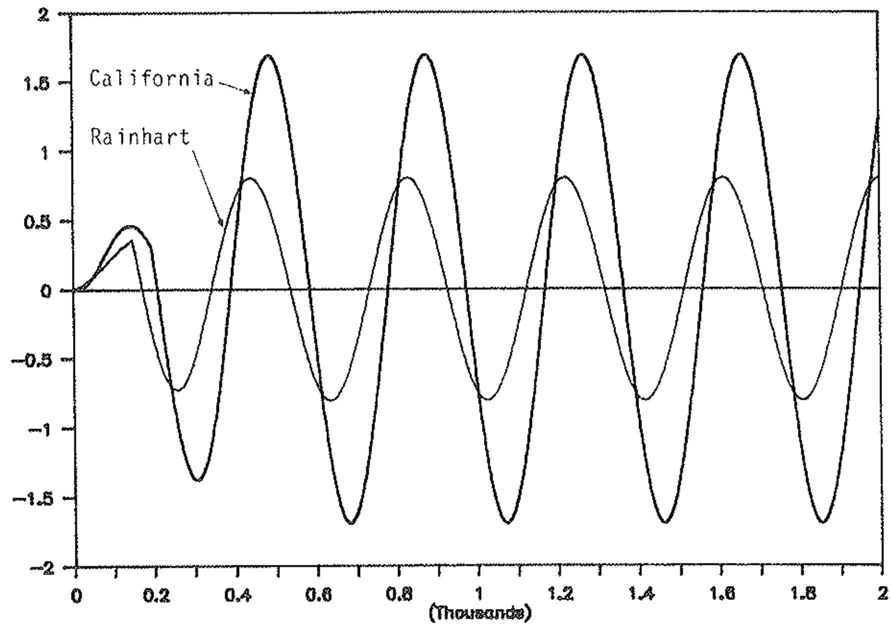

FIGURE 2 Responses of unit sinusoidal profile (period = 390 inches).

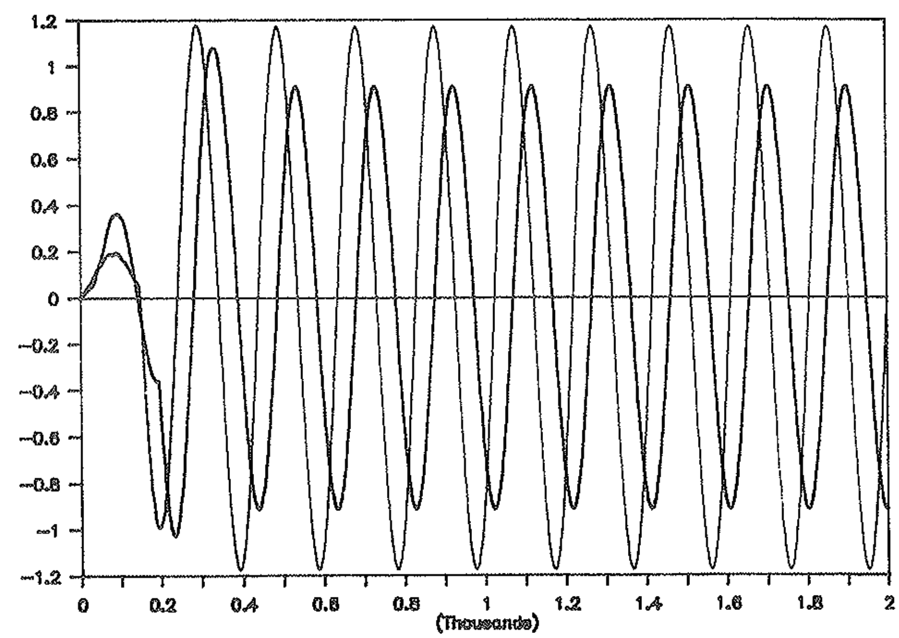

FIGURE 3 Responses of unit sinusoidal profile (period = 195 inches).

is reversed in the shorter wave period case, as shown in Figure 3.

The models can be used to investigate the response of the profilographs under various profile wavelengths. Figures 4 and 5 depict the maximum amplitude recorded from both models under sinusoidal style profiles of unit amplitude but with different wave periods. It is interesting to note that the models, and thus the actual profilographs, show amplification and attenuation with respect to different wave lengths. Since the model uses a point contact wheel assumption, it generates a profilogram even for very small wavelengths. In the actual profilograph device, wavelengths shorter than the wheel-pavement contact length cannot be measured. It is difficult to estimate the exact wavelength for this cut-off region. However, results of wavelengths greater than, say, about 0.2 feet should closely resemble the actual profilograph output.

Also note that the maximum amplitude recorded can reach as high as twice (approximately 1.9) the input sine wave amplitudes for the two models. However, the position of these peaks occurs at different sine wave periods for different profilographs. Since the Rainhart profilograph has equal wheel adjacent distance in the longitudinal direction, the maximum amplitude predicted could reach as high as twice the input amplitude when the wave period matches the wheel patterns.

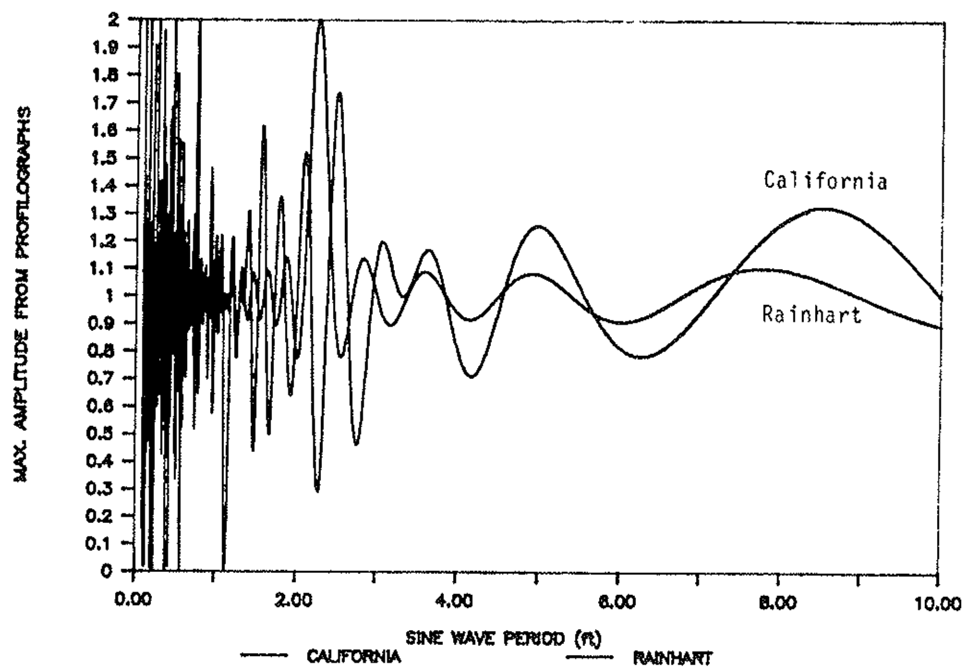

FIGURE 4 Frequency responses of profilographs.

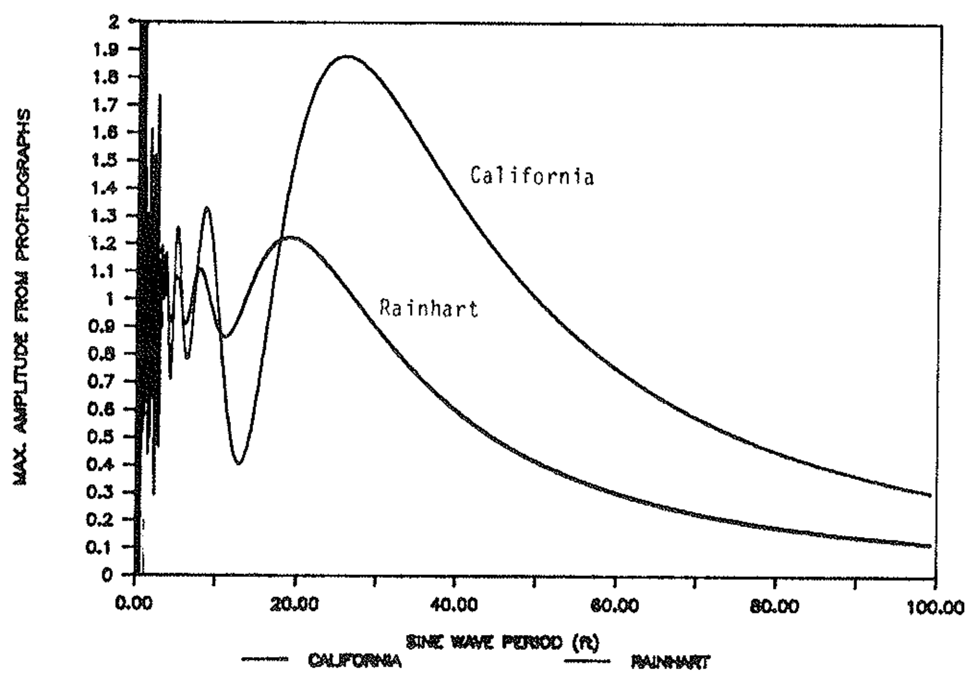

FIGURE 5 Frequency responses of profilographs.

As the wavelength increases beyond 25 feet (20 feet for Rainhart device), both models predict smaller maximum amplitude. It is also observed that the maximum amplitude recorded decreases smoothly for waves with lengths greater than the profilograph. At a wavelength of 100 feet, it records about 35 percent of the input wave amplitude for the California profilograph and about 15 percent for the Rainhart profilograph. One other observation is of interest. For wavelengths above about 18 feet, the California device response is greater than the Rainhart device. This might account for the different blanking band requirements in order to get similar amplitude results.

Spectral Analysis of Pavement Profiles

The power spectral estimates of the road profiles, in conjunction with the frequency response of the profilographs,

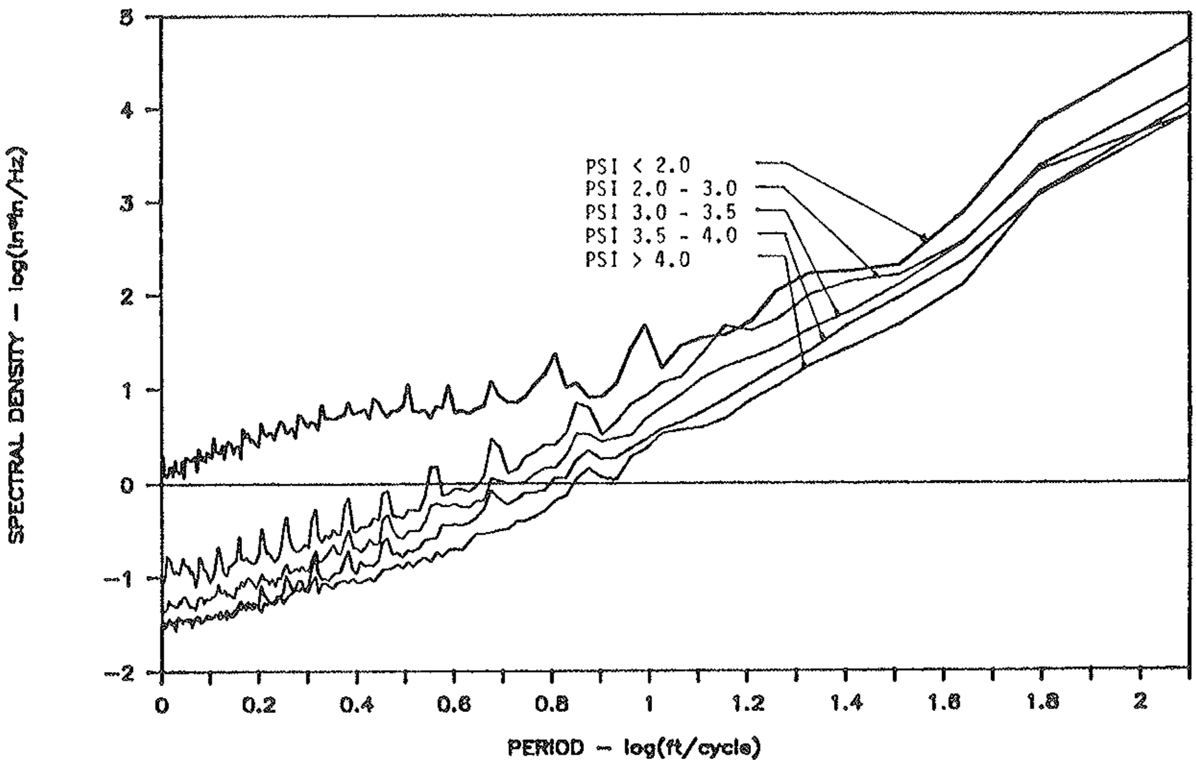

FIGURE 6 Pavement spectral density.

could be useful in investigating the measurement capabilities of the profilographs. For example, it is noted that the profilographs will underestimate some frequencies and overestimate or exaggerate others. If the sections investigated in this or other studies represent the population of rigid pavements and the profilograph measurement effects are well correlated to ride, then the devices would be useful for construction control. On the other hand, if a new construction method adds frequencies in the range that is over- or underestimated, then undesirable results could be obtained.

The power spectral estimates were run on all 41 sections and the average power presented in plots for various roughness classes in Figure 6. These estimates could be useful in comparing the road frequencies with the way the profilographs measure the various profile wavelengths. Also, the response of the statistics used in determining the PSI values from the SDP, RMSVA, and slope variance values from the WRD could be investigated. These results are included to indicate a future research area.

DATA ANALYSIS

In this section the data collected will be correlated and presented. First, a comparison between the Rainhart and California profilographs will be shown. This comparison will include the Rainhart versus California units for 0.1- and 0.2-in. blanking bands. Also each profilograph will be compared with the other for each of these two bands. The two profilographs will then be compared with PSI from the SDP. This comparison will include all sections, then only those with a profile index less than 20, since this is in the range where most new pavement construction would likely fall. A comparison between the WRD and the two profilographs is given. Finally, a comparison between the WRD and SDP is presented. Table 2 provides the equations for the linear regressions used.

California versus Rainhart Profilographs

As indicated earlier, profile indexes from the 41 sections were computed for both profilographs and for both the 0.1- and 0.2-in blanking bands. A simple linear regression was computed for each combination (the regression coefficients are given in Table 2). The correlation coefficient and standard error of regression are indicated. The independent variable used for each case is the variable along the *x*-axis, although no reason was used in selecting one particular variable over the other as the independent or dependent variable.

Figure 7 illustrates the relationships between the California profilograph using the 0.1-in blanking to the 0.2-in blanking. As previously discussed, the currently accepted practice has been to use the 0.2-in blanking band when computing the profile index for the California profilograph. As one would expect, there is a high correlation between these two plots: an R^2 of 0.99. The 2.38 standard deviation reflects both the differences in the measurement process and the human errors in computing the profile index. The measurement error in the reading of the profile index from the charts was typically about one profile index value.

Figure 8 depicts the relationship between the 0.1- and 0.2-in blanking bands for the Rainhart profilographs. As can be noted, the correlation and standard error of regression is not as good, 0.91 and 4.78 respectively. This difference could

TABLE 2 COEFFICIENTS OF REGRESSION MODELS

Dependent Variable	Independent Variable	Regression Constant	Coeff. Linear	Standard Err.	R Squared
CPI_0.2"	CPI_0.1"	-5.275	0.8577	2.379	0.989
RPI_0.2"	RPI_0.1"	-4.052	0.7642	4.783	0.911
RPI_0.1"	CPI_0.1"	-4.710	0.7537	3.670	0.966
RPI_0.2"	CPI_0.2"	-4.352	0.6829	4.517	0.921
RPI_0.2"	CPI_0.1"	-7.789	0.5804	5.220	0.894
RPI_0.1"	CPI_0.2"	-0.024	0.8764	3.344	0.972
PSI	CPI_0.1"	4.629	-0.03881	0.2230	0.742
PSI	CPI_0.2"	4.443	-0.04762	0.2335	0.705
PSI	RPI_0.1"	4.477	-0.06946	0.1907	0.824
PSI	RPI_0.2"	4.255	-0.1111	0.2632	0.628
PSI	SCPI_0.1"	5.199	-0.3147	0.2789	0.856
PSI	SCPI_0.2"	4.819	-0.3049	0.2799	0.855
PSI	SRPI_0.1"	4.771	-0.3161	0.2835	0.852
PSI	SRPI_0.2"	4.344	-0.3118	0.3403	0.786
WRD_SI	sqrt(CPI_0.2")	4.765	-0.2897	0.1933	0.901
WRD_SI	sqrt(RPI_0.1")	4.696	-0.2920	0.2119	0.882
PSI	log(WRD_SV)	8.432	-1.8281	0.2246	0.882

Note:

CPI: California Profile Index
RPI: Rainhart Profile Index
PSI: SDP Profile Service Index
WRD_SI: WRD Serviceability Index
WRD_SV: WRD Slope Variance (unscaled)
SCPI: Square root of CPI
SRPI: Square root of RPI

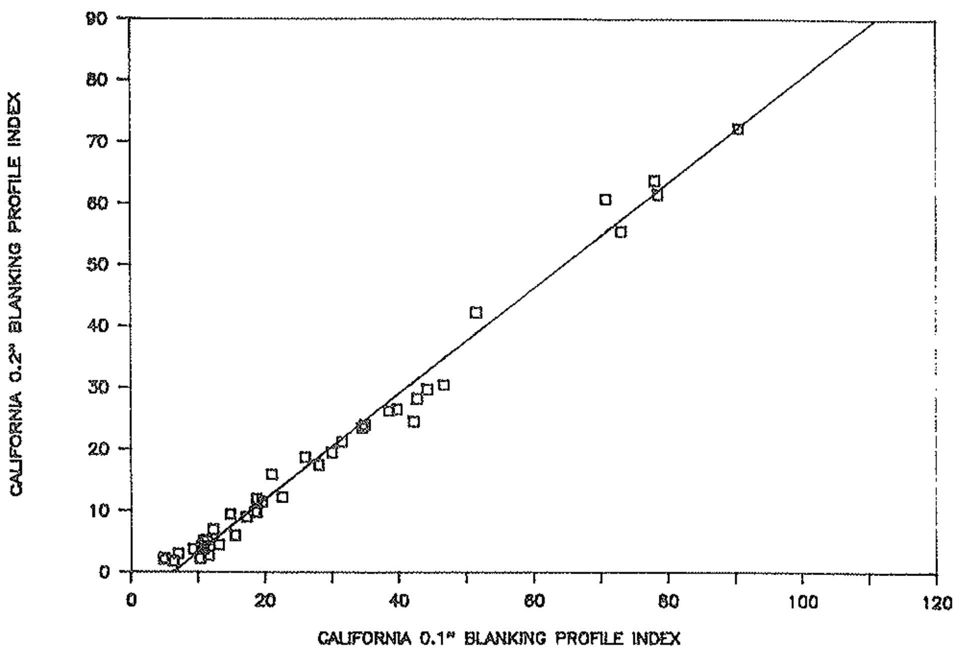

FIGURE 7 California 0.2-in versus 0.1-in blanking band profile index.

likely be explained by recalling the frequency response characteristics illustrated in Figure 4. Recall from this figure that the California device gave a much greater response to many of the frequencies than the Rainhart device, almost twice as much in some cases. This greater sensitivity to roughness values could account for the correlation differences. For example, one would expect a similar, or even poorer, correlation if 0.2- and 0.3-in blanking bands had been used for the California device. The 0.2-in blanking band does not measure as much roughness.

Figures 9 through 12 show the correlations between the two devices for each blanking band. Figure 9 illustrates the differences between the California and Rainhart devices for a 0.1-in blanking band and Figure 10 for the 0.2-in blanking band. Figure 11 illustrates the 0.1-in blanking band for the California vs. the 0.2-in blanking band for the Rainhart, and figure 12 illustrates the reverse. Notice that the California 0.2-in blanking band versus the Rainhart 0.1-in blanking band provides the best correlation and standard error of 0.97 and 3.34. The 0.1-in vs. 0.1-in blanking bands in figure 9 also has a 0.97 correlation but a slightly higher standard error, 3.67. However, when the 0.2-in blanking band is used for the Rainhart device the correlation and standard error get worse.

From these results, the standard practice of using a 0.1-in blanking band for the Rainhart device and a 0.2-in blanking band for the California device appears to be the best com-

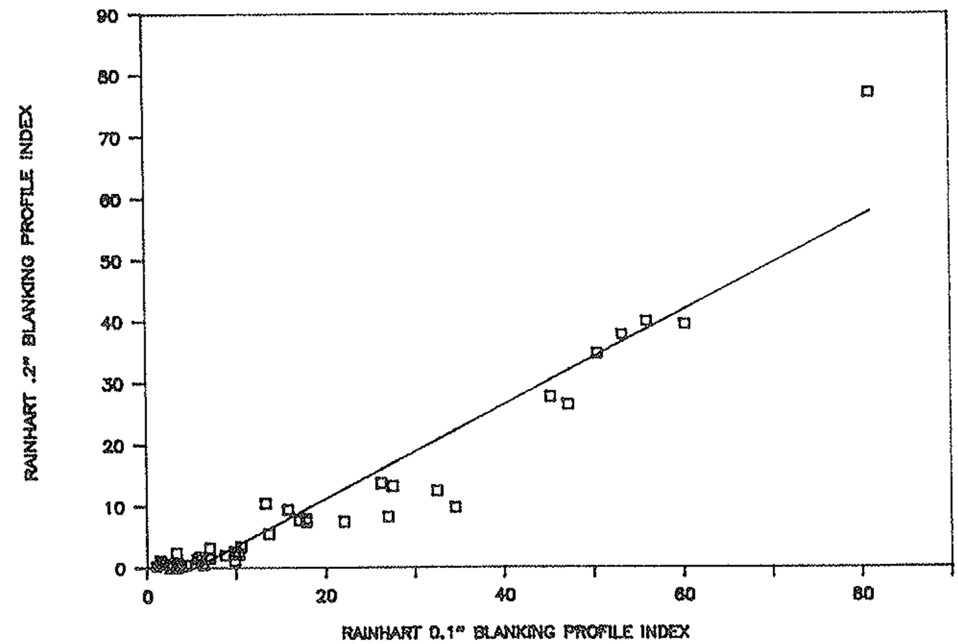

FIGURE 8 Rainhart 0.2-in versus 0.1-in blanking band profile index.

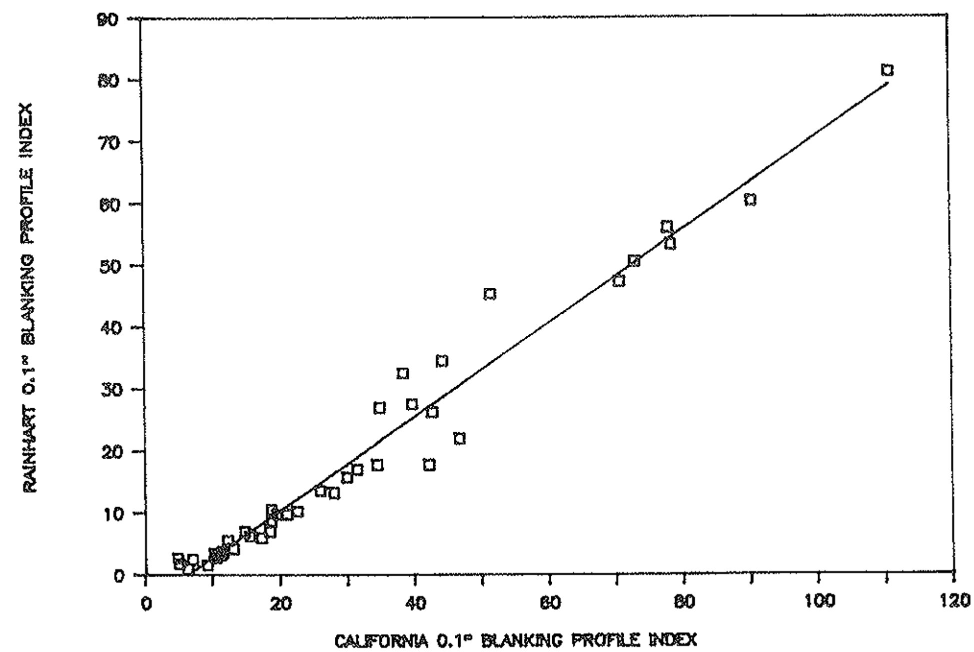

FIGURE 9 Rainhart 0.1-in versus California 0.1-in blanking band profile index.

bination. The 0.1-in blanking band used for the California unit gives close to the same results as the 0.2-in blanking band; however, the 0.2-in blanking band used for the Rainhart profilograph appears to lose too much roughness information.

California and Rainhart Profilograph versus PSI

Figures 13 through 16 provide relationships between PSI from the SDP and profile index for all sections used and for both profilographs and blanking bands. Figures 17 through 20 provide similar information, except that a square root transformation has been applied to the PI values and a regression performed with PSI. From these figures it is noted that the California 0.1-in and 0.2-in blankings give the same results (RSQ = 0.86 and STD = 0.28). The Rainhart 0.1-in blanking, once again, appears superior to the 0.2-in blanking as the R^2 drops from 0.85 to 0.79. The variation between PSI and profile index is greater for the rougher sections, as one would expect. Figures 21 through 24 provide relationships of

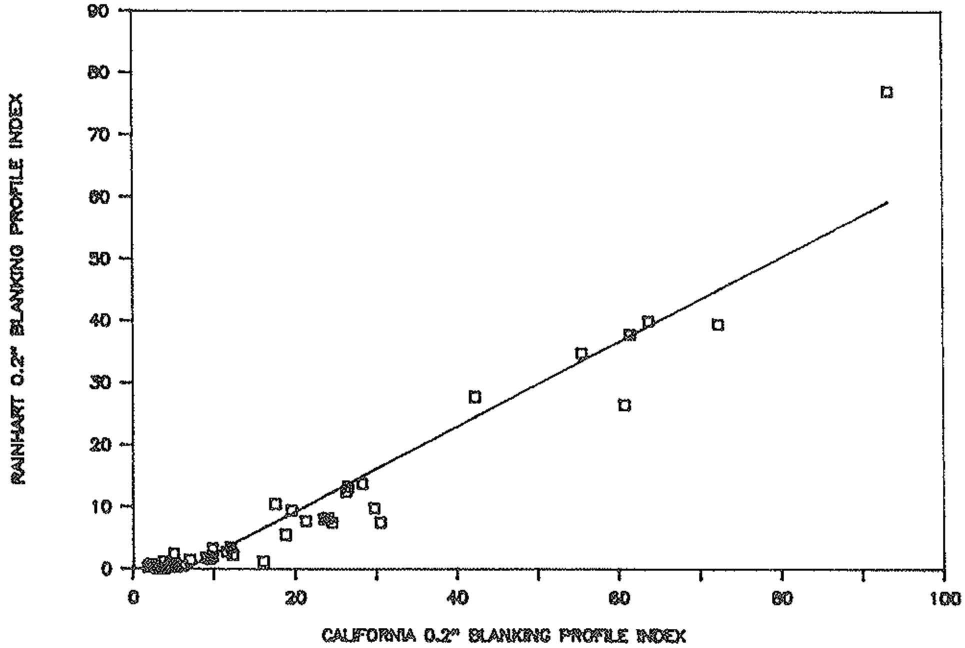

FIGURE 10 Rainhart 0.2-in vs. California 0.2-in blanking band profile index.

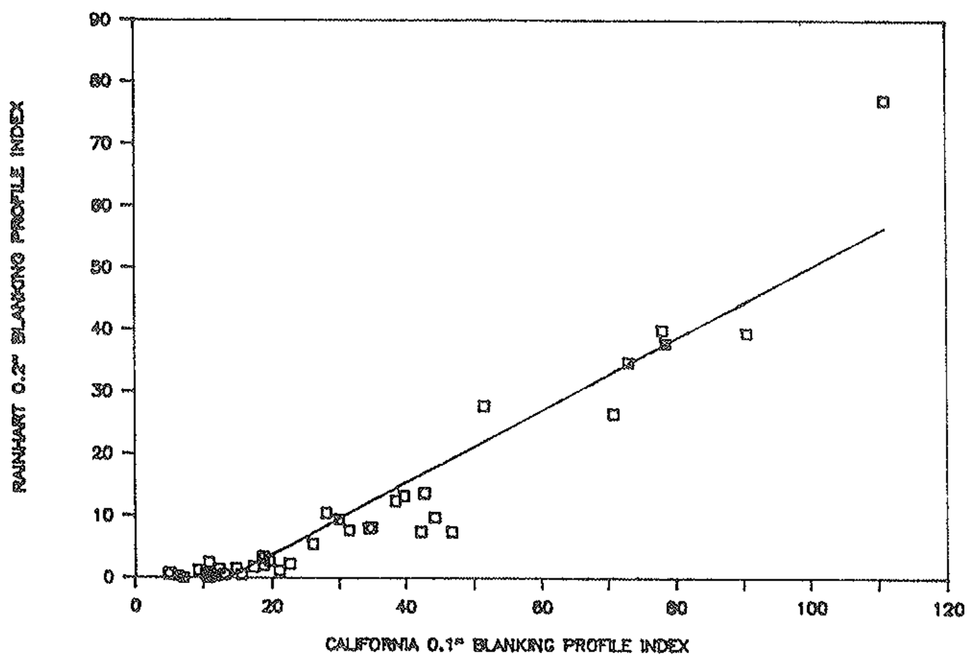

FIGURE 11 Rainhart 0.2-in vs. California 0.1-in blanking band profile index.

the smoother sections, or those with a profile index of 20 or less, as measured using the 0.2-in blanking band on the California profilograph. This range was selected, as the greater use of the profilograph has been in construction control for new pavements where pavements with a profile index of 12 or less are usually considered acceptable. The 0.2-in blanking band data of the Rainhart device once again gave the poorest results. However, the 0.1-in blanking band for the California unit gave somewhat better results than the 0.2-in blanking band. As previously indicated, the same set of sections was used in all cases. The Rainhart 0.1-in blanking gave the better results.

In these figures, a linear regression was performed between PSI and profile index. The regression line is shown along with the 90 percent confidence bands. It should be noted that, in regression, the independent variable is the one considered with the least error. If the PSI is the standard, then one might want to regress the other way or use an inverse regression. Since we wanted to examine the standard error of the PSI values, and were really not sure which had the least error,

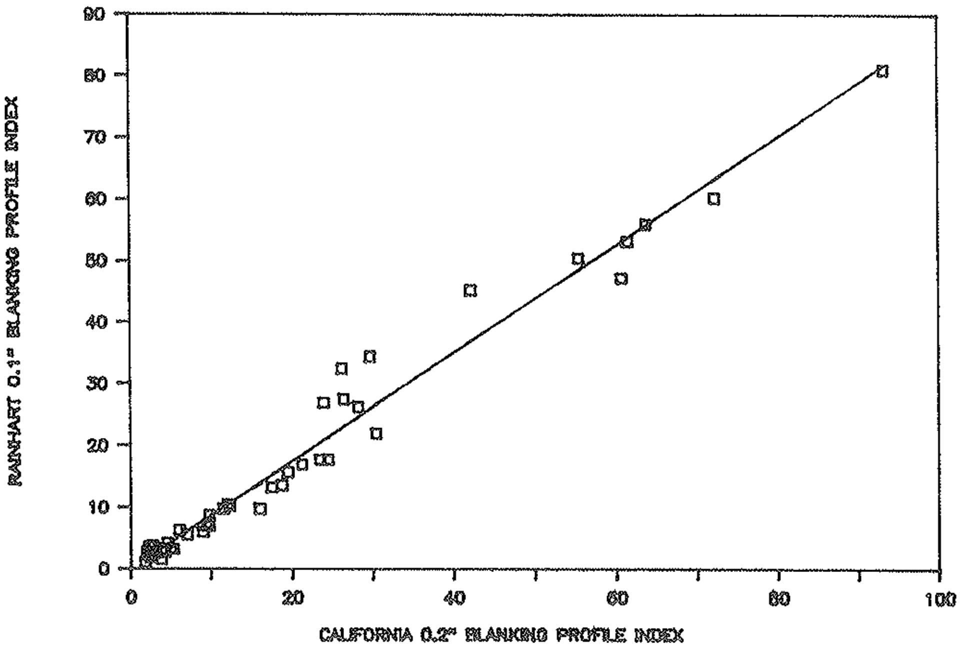

FIGURE 12 Rainhart 0.1-in vs. California 0.2-in blanking band profile index.

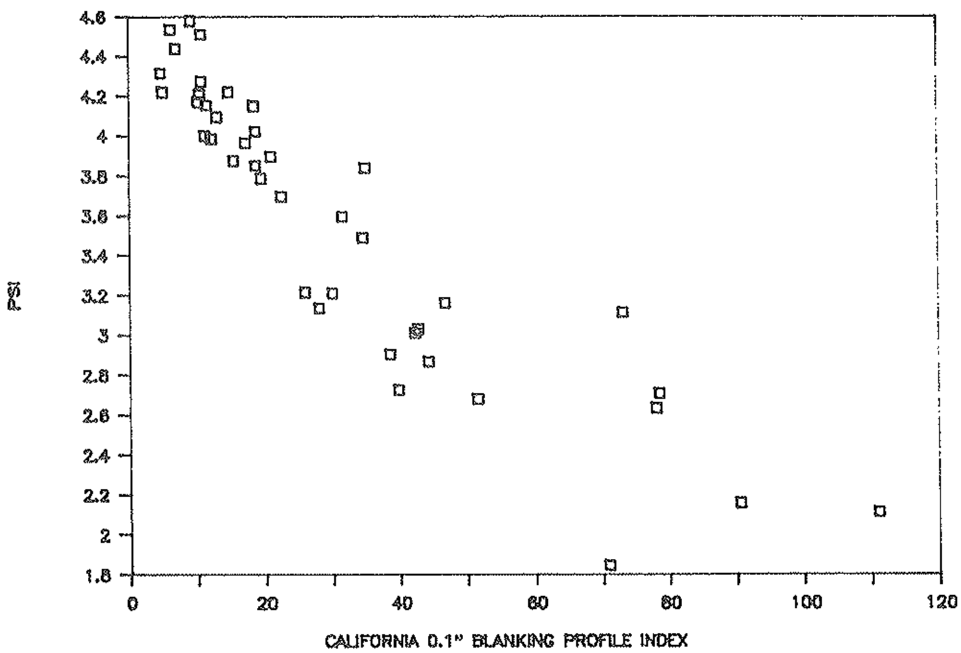

FIGURE 13 PSI vs. California 0.1-in blanking band profile index.

the regression was performed as indicated. From the figures, the range of profile index values for various PSI values can be investigated.

California and Rainhart Profilographs vs. WRD

Figures 25 and 26 provide the correlations found between SI predicted by the WRD and profile index. Only the profile index values using the 0.1-in and 0.2-in blanking bands are given. The others were slightly less correlated as found above. As also noted in Chapter 2, not all the sections were included. The SI values shown are obtained from the regression performed in the next section, relating the WRD slope variance statistic to PSI. As noted, a slightly higher correlation was obtained between SI from the WRD than PSI with the SDP (0.88 vs. 0.86 for the California). An R^2 of 0.91 was obtained when the slope variance statistic was correlated directly to the profile index from the California profilograph. The SI values currently used with the WRD are those modeled from flexible pavements. Since the PSI model for the SDP is different for flexible and rigid pavements, these SI values were not used.

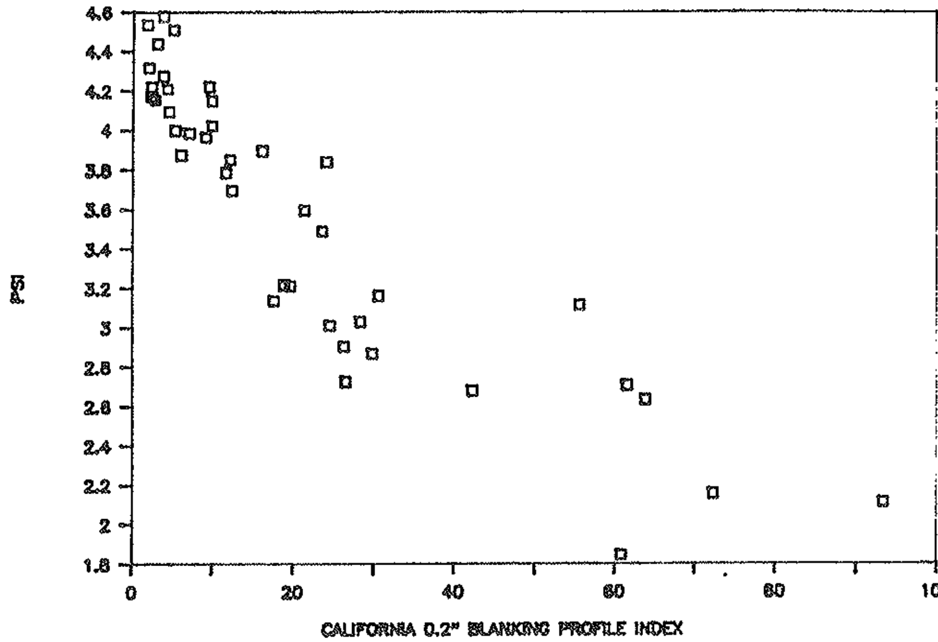

FIGURE 14 PSI vs. California 0.2-in blanking band profile index.

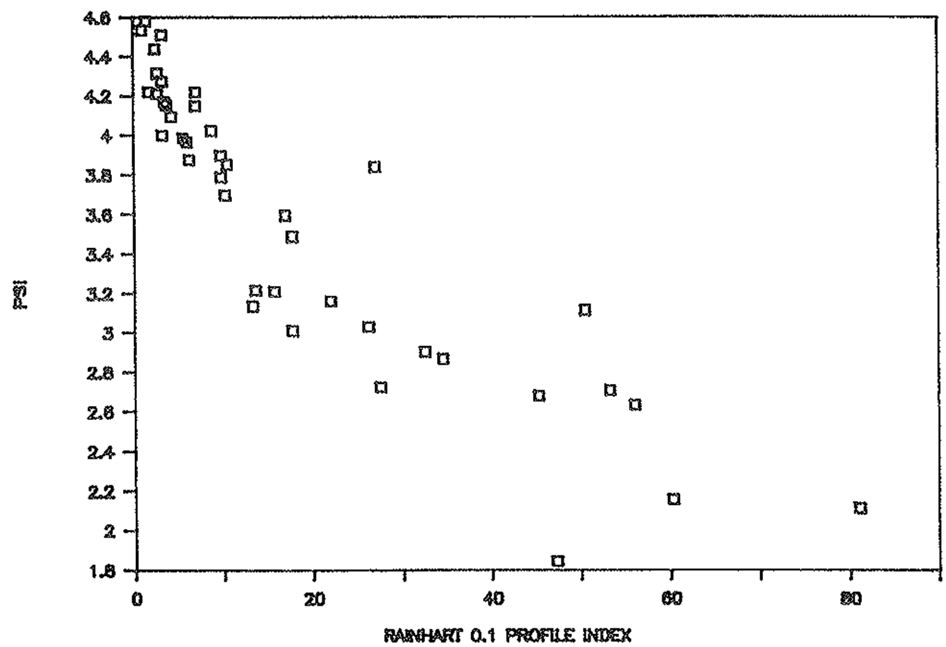

FIGURE 15 PSI vs. Rainhart 0.1-in blanking band profile index.

CONCLUSIONS

This research effort was initiated to determine relationships between roughness measurements from the California and Rainhart profilographs and PSI.

The research indicated that there exists a high correlation between the Rainhart and California profilographs. The best correlation found between the two devices from the sections tested was when a 0.1-in blanking band was used for the Rainhart device and a 0.2-in blanking band was used for the California device. The most common practice has been to use this combination. Using a 0.1-in blanking band for the California device gave good results. It gave better results for the correlation done with PSI on the smoother pavements. However, using a 0.1-in blanking band for the Rainhart profilograph gave significantly better results than the 0.2-in blanking band. The California profilograph was easier to operate.

A good correlation was found between PSI from the SDP and the profile index from the two profilographs. For all sections investigated, the California profilograph correlated

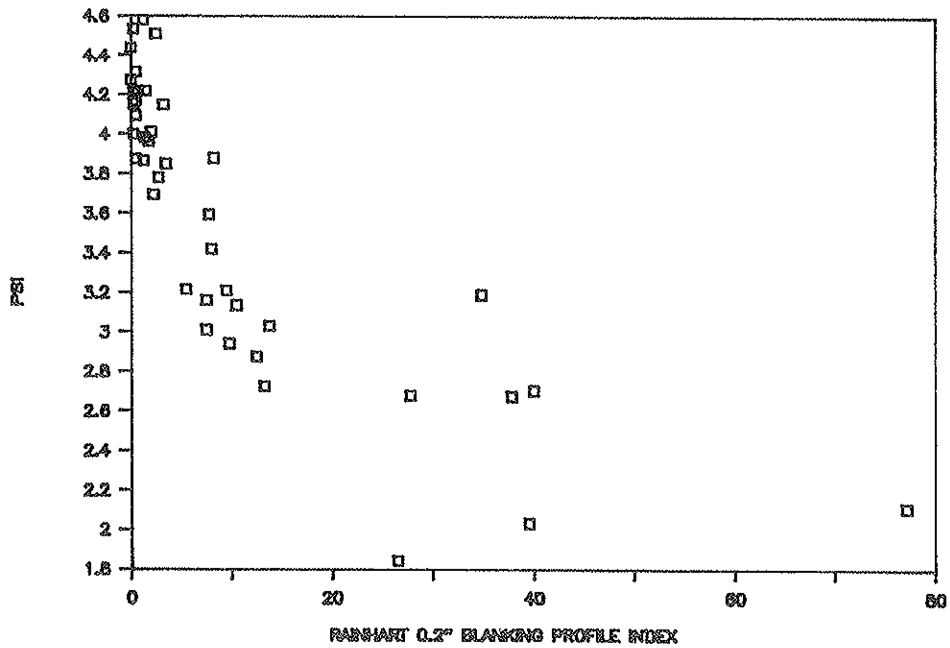

FIGURE 16 PSI vs. Rainhart 0.2-in blanking band profile index.

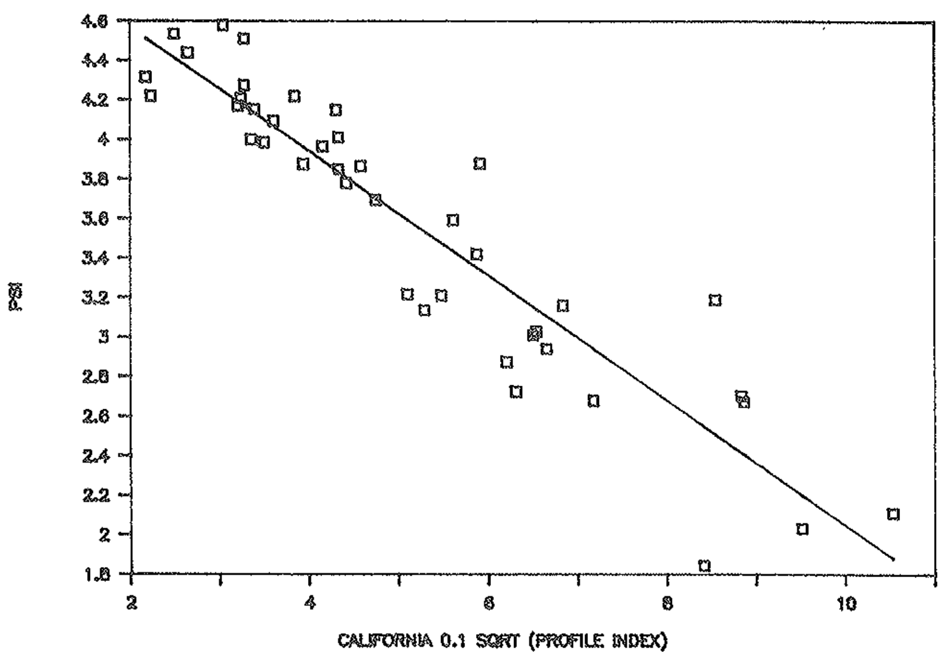

FIGURE 17 PSI vs. square root of California 0.1-in blanking band profile index.

slightly higher to PSI than the Rainhart. The current model used for computing PSI from the SDP does not appear to give many sections with PSI values much greater than 4.5. This made it difficult to get many sections above 4.5, which is needed to establish points in this upper range. The Rainhart profilograph using the 0.1-in blanking band gave the best results for the smoother pavements.

A good correlation was also found between SI and the slope variance statistic provided by the WRD and the profilographs. The California profilograph also was found to be slightly better correlated.

This study is useful for investigating PSI relations with profile index and in comparing data from the two profilograph types. As noted, the Rainhart and California Profilographs are currently being used by several states for construction control measurements and may be the best devices for such measurements. The profilograph is less expensive than most currently used roughness measuring devices, is easy to under-

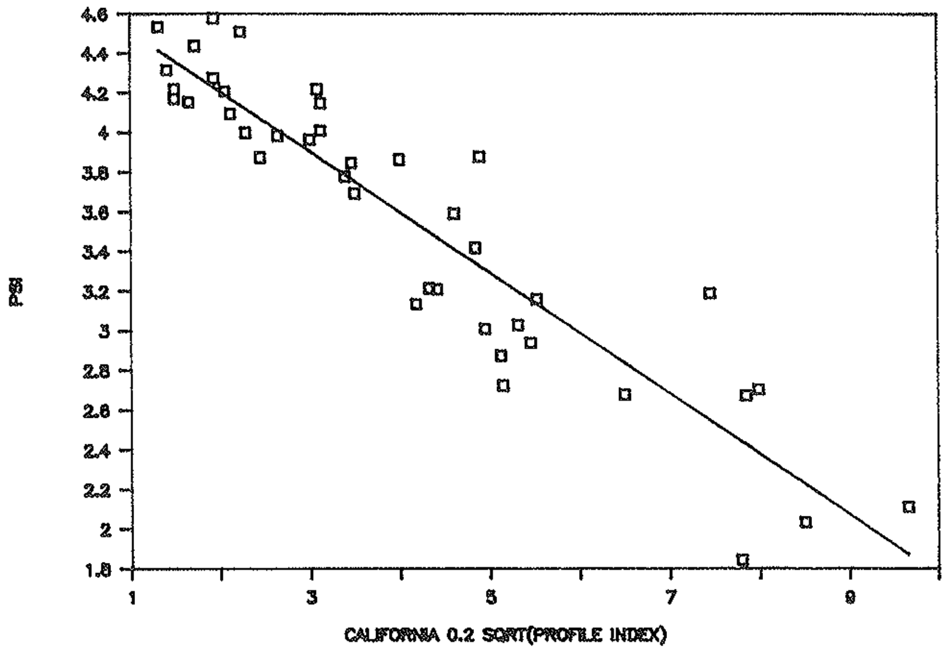

FIGURE 18 PSI vs. square root of California 0.2-in blanking band profile index.

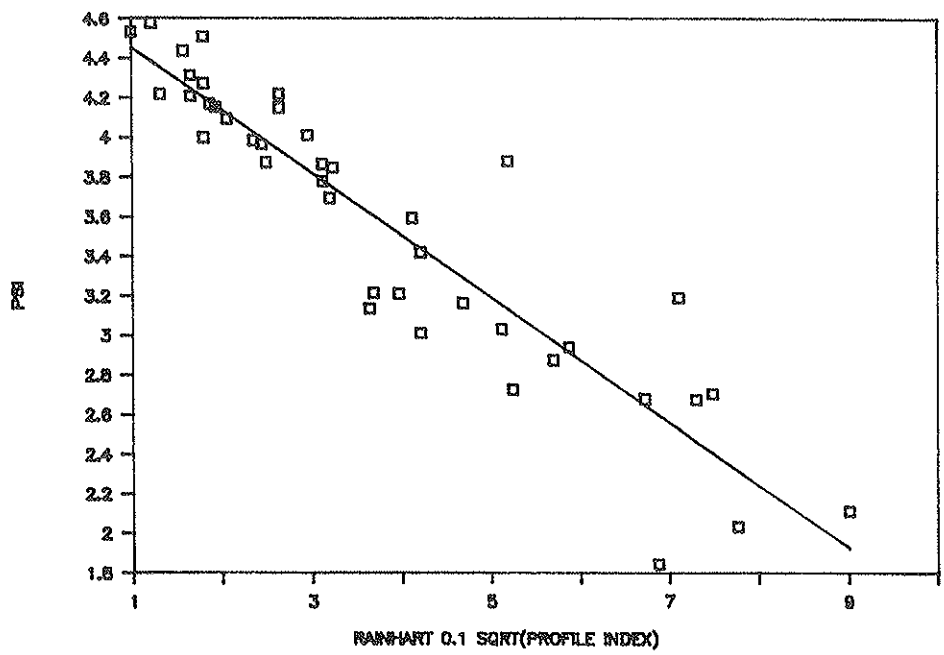

FIGURE 19 PSI vs. square root of Rainhart 0.1-in blanking band profile index.

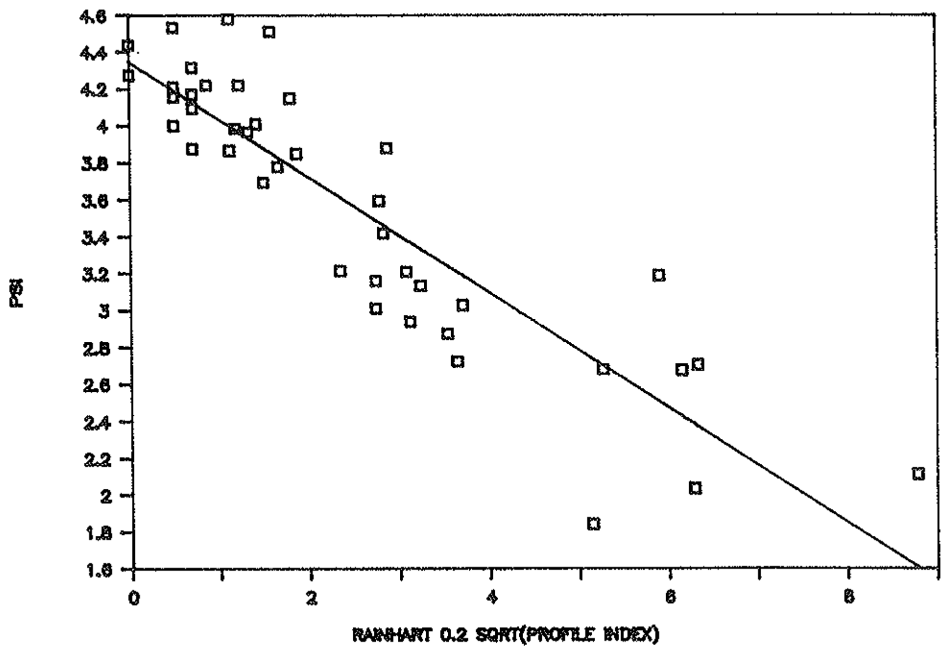

FIGURE 20 PSI vs. square root of Rainhart 0.2-in blanking band profile index.

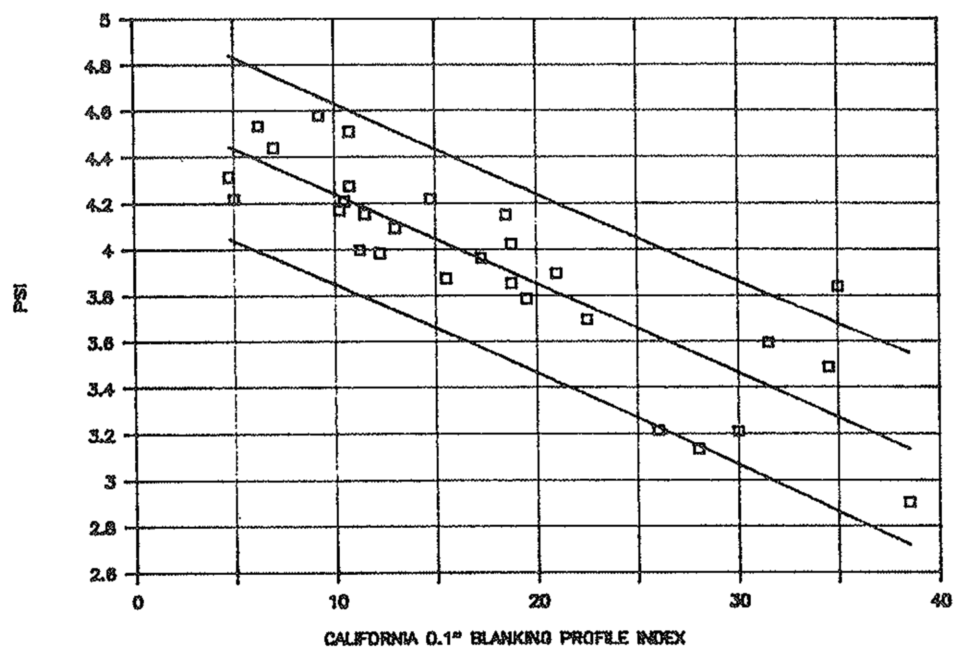

FIGURE 21 PSI vs. California 0.1-in blanking band profile index with 90 percent confidence band.

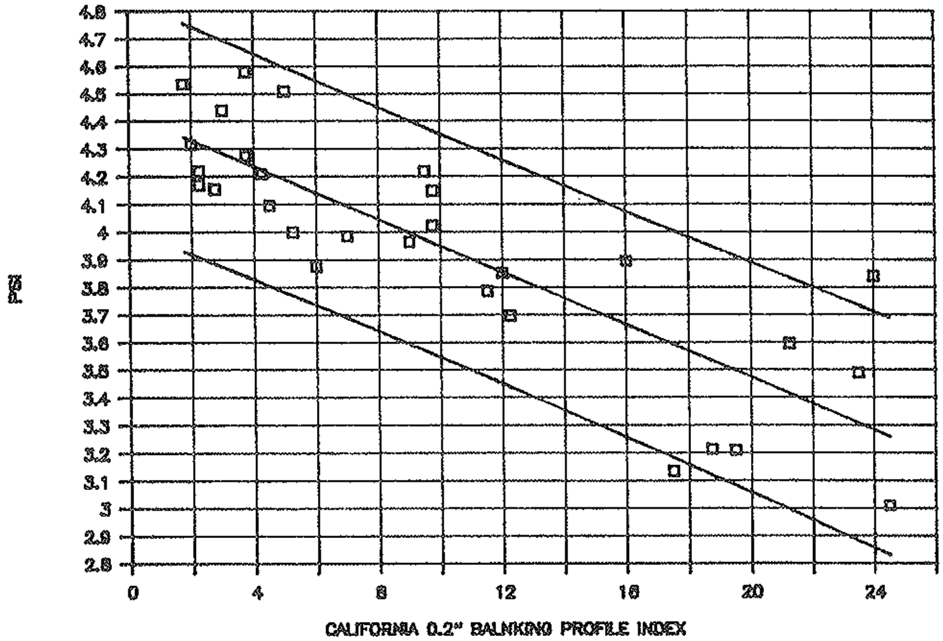

FIGURE 22 PSI vs. California 0.2-in blanking band profile index with 90 percent confidence band.

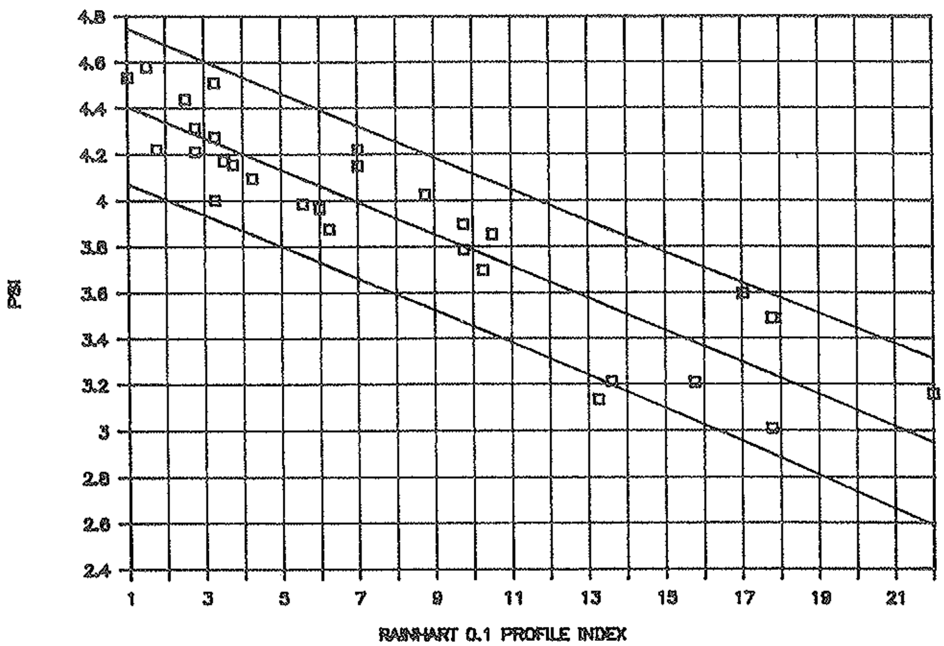

FIGURE 23 PSI vs. Rainhart 0.1-in blanking band profile index with 90 percent confidence band.

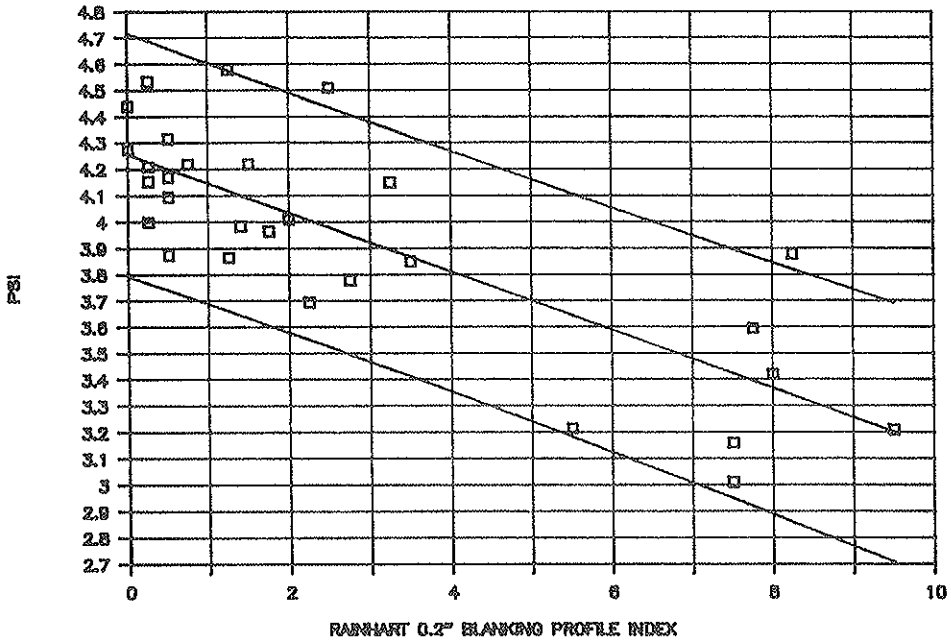

FIGURE 24 PSI vs. Rainhart 0.2-in blanking band profile index with 90 percent confidence band.

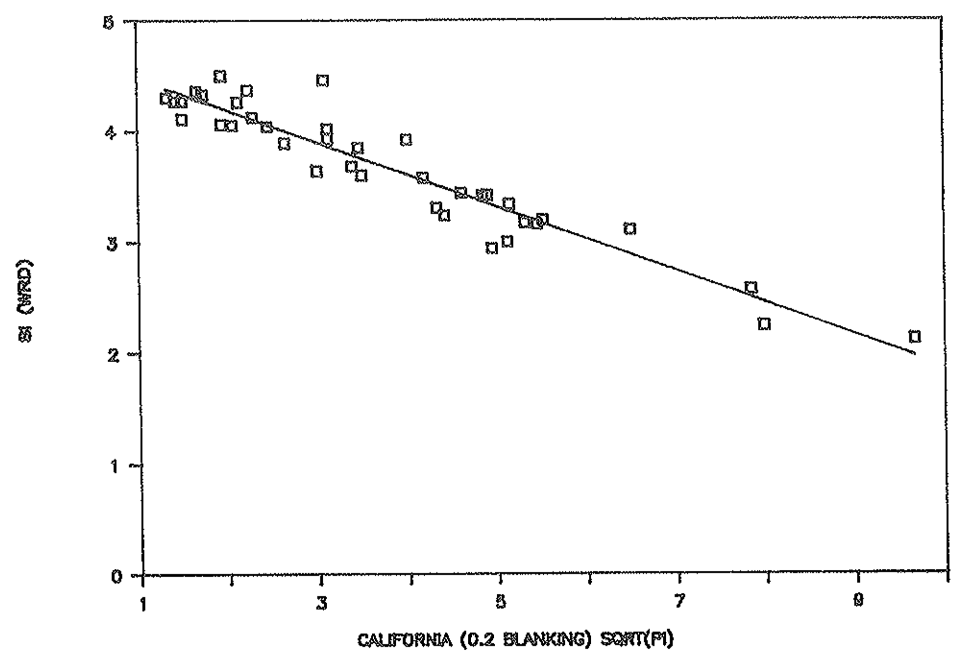

FIGURE 25 California 0.2-in blanking band profile index vs. WRD serviceability index.

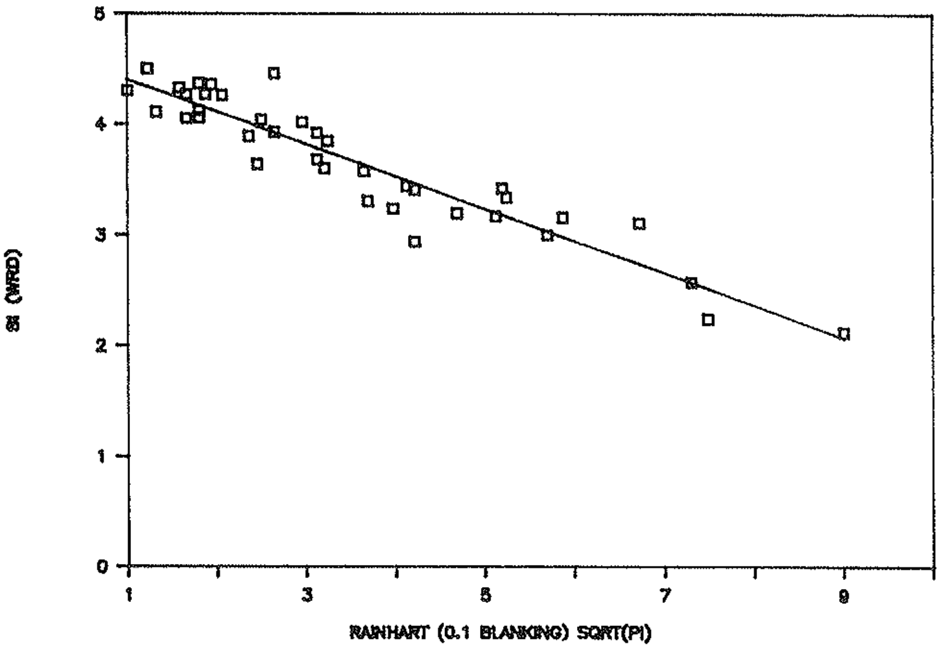

FIGURE 26 Rainhart 0.1-in blanking band profile index vs. WRD serviceability index.

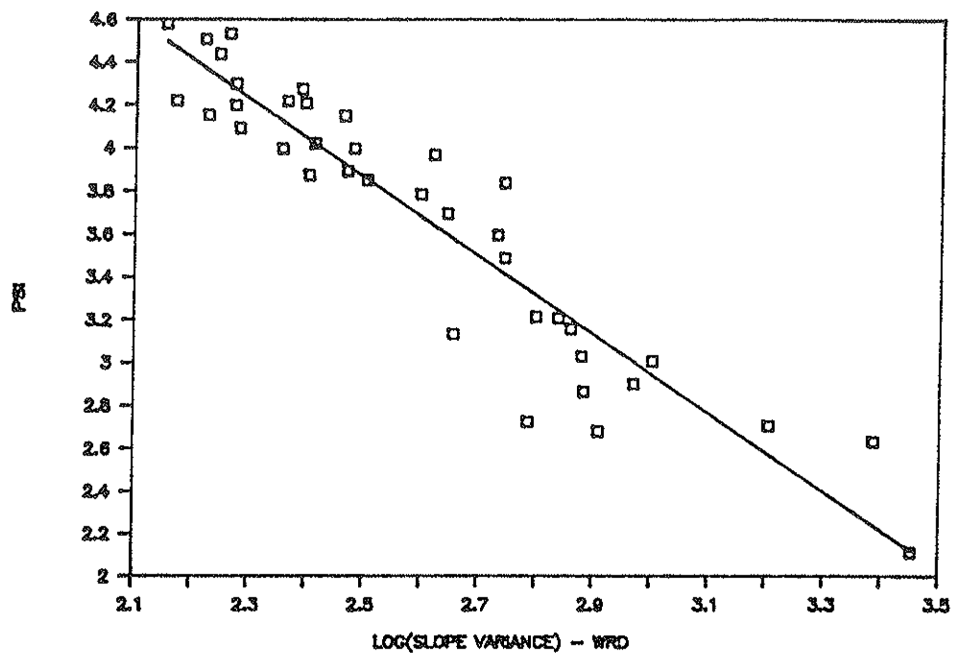

FIGURE 27 PSI vs. WRD log (slope variance).

stand, has a low operations cost, and requires no special skills from the operator. However, the frequency response of these two devices to road profile are such that the effects of some roughness frequencies can be underestimated and others overestimated. Thus, although such devices may be best, particularly for new construction, based on the models developed, they do appear to have certain limitations.

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