Evaluation of the Siometer as a Device for Measurement of Pavement Profiles

EMMANUEL G. FERNANDO, ROGER S. WALKER, AND ROBERT L. LYTTON

Highway engineers have always been concerned with providing pavements of acceptable serviceability. The serviceability of a highway segment, which is largely a function of pavement roughness, is a widely used criterion for deciding when pavements are in need of rehabilitation. For this application, various statistics are currently used as indicators of pavement serviceability, the most common being the present serviceability index. These statistics are largely determined from measurements of pavement roughness. Various devices and procedures have been developed for accomplishing these measurements. Of practical necessity, devices for measuring pavement roughness must be capable of providing repeatable measurements at normal highway speeds. In addition, devices that do not require difficult calibration procedures, that possess the capability for field processing of the data collected, and that are relatively inexpensive to own, operate, and maintain are most desirable. The Siometer, which is currently used by the Texas State Department of Highways and Public Transportation (SDHPT) for evaluation of pavement riding quality, holds promise as an instrument for the routine collection of profile data on a network-wide scale. The Texas SDHPT has recently begun investigating the profile-measuring capability of the Siometer. A unique feature of this device is the statistical modeling procedure for characterizing the vehicle on which it is installed, which lends portability to the Siometer. In it, the parameters of the statistical model are determined in a self-calibration procedure that is run before profile data are collected. To evaluate the applicability of the Siometer as a device for profile measurements, profile measurements with the Siometer were compared with those from a profilometer.

Pavement roughness is the principal determinant of riding quality as perceived by the road user. In order to provide roads that offer a smooth and comfortable ride, a transportation agency requires measurement techniques for quantifying pavement surface roughness. An evaluation was made of a profile-measuring device known as the Siometer. This device, developed by Dr. Roger Walker of the University of Texas at Arlington, is used by the Texas State Department of Highways and Public Transportation (SDHPT) for evaluating the riding quality of pavement sections in the state.

Pavement surface profiles measured with the Siometer were compared with those determined from the surface dynamics profilometer (SDP). Over the years, the SDP has gained wide acceptance as a device for evaluating pavement profiles. It is classified as a Class 2 instrument by the World Bank (*1*) for the measurement of the international roughness index (IRI).

The SDP was designed by General Motors and built by K. J. Law Engineers in 1967. Originally, it had as primary sensors two accelerometers and two linear potentiometers, connected to road-following wheels. The accelerometers determine the amount and direction of vertical acceleration experienced by the vehicle, whereas 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 (*2*). In the latest version of this device, the potentiometers and road-following wheels have been replaced by noncontact sensors.

The SDP is capable of measuring profiles of considerable accuracy and consistency at normal highway speeds without the need for calibration. It has been used as a reference device for measurement of present serviceability index (PSI) within the Texas SDHPT. The principal statistic currently used by the Department in computing PSI from profile data is the root-mean-square vertical acceleration (*3*).

Although the SDP provides a fairly rapid and accurate method of determining pavement profiles from which various roughness statistics can be computed, it requires a large initial capital outlay and is relatively expensive to operate. Consequently, many state transportation agencies generally use response-type road roughness measuring devices, such as the Mays meter, for collecting roughness data on a network-wide basis. However, such devices require periodic calibration, which often entails significant effort. What is clearly needed is a device that can be used to collect fairly accurate and consistent profile data at normal highway speeds, that is relatively inexpensive to own and operate, and that does not require difficult calibration procedures. A device that has the potential of offering all of these advantages is the Siometer. The applicability of this device for measuring pavement profiles is evaluated in the following sections.

THE SIOMETER

The development of the Siometer was initiated by Walker during the early 1970s. A unique feature of this device is the statistical modeling procedure for characterizing the vehicle on which it is installed. Through this procedure, the influence of the vehicle on the measurement process is identified and removed (*4,5*). The statistical model is parameterized with the Siometer's on-board microcomputer using vertical accelerations of the vehicle measured at fixed distances as the vehicle is driven down the road. Vertical accelerations are obtained from an accelerometer that is housed in a small case and installed in the trunk of the vehicle. Once the parameters of the vehicle are determined, the Siometer is calibrated and

E. G. Fernando and R. L. Lytton, Texas Transportation Institute, Texas A&M University, College Station, Tex. 77843. R. S. Walker, Department of Computer Science Engineering, The University of Texas at Arlington, Arlington, Tex. 76019-0015.

ready for profile measurements. The vehicle is then driven over the roadway sections for which profiles are to be determined and the resulting accelerations are measured. The differences between the actual measurements and those predicted from the statistical model are used to estimate the road profile by integrating the acceleration differences with the time between successive samples.

The primary application of the Siometer within the Texas SDHPT is for evaluation of riding quality. Thus, the device became known as the Siometer because its primary output is the serviceability index (SI) for a particular pavement section, even though the SI is calculated using statistics derived from the predicted road profile. The device is portable and can be easily transferred from one vehicle to another. Furthermore, because it implements a self-calibration procedure, the device, in theory, can be installed in any vehicle because the effect of the vehicle is modeled in the same process.

The current version of the Siometer used by the Texas SDHPT is the R680 system manufactured by Micro-sher Incorporated. The R680 system consists of three components, namely (a) a sensor unit, (b) a main control module, and (c) a laptop computer for storing the results. The system computes and displays SI and predicts the pavement profile. The sensor unit and the main control module currently cost $20,000. The laptop computer can be purchased separately by the user from any other vendor.

The sensor unit includes the accelerometer and a distance-measuring signal. The accelerometer is housed in a small case that is weighed down with a sandbag and mounted vertically inside the trunk of the vehicle, where it measures the vertical acceleration. The signal from the accelerometer is transmitted to the main control module where it is digitized in accordance with the distance signal and processed.

The main control module contains two Motorola 68000 microprocessors working in parallel. One performs input-output operations and the other performs numerical computations.

The data storage component is a portable laptop computer. A communications program provides the interface between the control module and the laptop computer. This program and the personal computer provide the means of obtaining continuous SI or profile measurements. The entire Siometer system is portable and can be easily installed in most standard vehicles.

An enhanced version has also been developed that implements the South Dakota method of measuring longitudinal profiles. The South Dakota profiler, currently considered by many to be a Class 2 instrument, is becoming a popular device for measuring pavement profiles. This device measures pavement profile elevations by the use of an accelerometer and acoustic sensors, which perform the same function as the laser probes in the SDP. The South Dakota profiler differs from the SDP in this respect and also in the procedure used for integrating the accelerometer signal. The current version of the device measures longitudinal profile elevations at the inner wheelpath and also provides estimates of pavement rutting using data from the acoustic sensors. At present, the roll of the vehicle is not considered in the determination of pavement rutting although numerous tests indicate reasonable agreement between rut depth data obtained manually and rut depth estimates from the profiler. Because the Siometer can easily implement the South Dakota profiler concept by the simple installation of acoustic sensors in the test vehicle, it has recently been upgraded for this purpose and is undergoing evaluation by the Texas SDHPT. In addition, to identify the influence of vehicle roll, the possibility of using additional accelerometers in conjunction with up to five acoustic sensors is being considered. This improvement will require modifications to the Siometer hardware, but consideration of vehicle roll will provide the Texas SDHPT with the capability of measuring transverse pavement profiles in addition to longitudinal profiles.

EVALUATION OF PAVEMENT PROFILES MEASURED FROM THE SIOMETER

The Texas SDHPT has recently begun investigating the profile-measuring capability of the Siometer. The findings presented herein are based on results obtained thus far. In order to evaluate the applicability of the Siometer for profile measurements, the SDP was used as a reference.

In this evaluation, nine bituminous test sections were selected on which profile measurements using the SDP and the Siometer were made. Three of the test sections were smooth, three were rough, and the other three were intermediate. All sections were 0.2 mi in length. The serviceability indices calculated from the SDP profiles on the nine selected sections are shown in Table 1. All sections, with the exception of TC7 in Tarrant County, are located within the general vicinity of Austin, Texas.

The pavement profiles of the nine sections were measured using the SDP and Siometer of the Texas SDHPT. The SDHPT's SDP is similar in design to that originally built by K. J. Law except that the potentiometer and road-following wheel combination has been replaced with two noncontact Selcom laser probes. This feature has reduced maintenance problems associated with the mechanical road-following wheels and has allowed profile measurements to be conducted at faster highway speeds. In addition, data acquisition and processing capability was upgraded to take advantage of improvements in hardware technology and thus allow data reduction to be conducted in the field. Consequently, roughness statistics and profile data can now be obtained as soon as a run is completed on a particular highway segment.

For each test section selected, two profile measurements were obtained from each device. Profile elevations were taken at 0.50-ft intervals along each 0.2-mi section. Because the Siometer was portable, the device could be installed inside the SDP van. This allowed profile measurements to be made simultaneously on both devices for any given run, thus eliminating errors associated with run-to-run variations, such as differences in wheelpaths tracked between runs, differences in vehicle track widths, and differences in starting times between profile measurements. All measurements were taken at 20 mph in an attempt to traverse the same wheelpaths each time a run was made on a particular section. On two of the rough sections (Sections 1 and 4), yellow dots painted at regular intervals on the wheelpaths were used to guide the direction of travel between runs.

In order to establish a benchmark for evaluating Siometer profiles, a comparison of the profiles from repeat runs of the SDP was initially made. Figure 1 shows a comparison of

TABLE 1 TEST SECTIONS WHERE PROFILE MEASUREMENTS WERE COLLECTED

Section	Location	Present Serviceability Index (PSI)*
1	Decker Lake Road West, approximately 0.2 miles west of FM 973	1.87
4	Decker Lake Road East, approximately 0.3 miles west of FM 973	1.30
7	U.S. 183 South, 1.5 miles north of Burleson Road	4.24
12	U.S. 183 North, 1.1 miles north of Burleson Road at one-way sign at cross-over north of creek	4.57
21	Pearce Lane West, approximately 0.9 miles east of FM 973	1.69
31	FM 685 North, approximately 0.2 miles north of Phillips 66 gas station	2.55
40	FM 973 South, 0.56 miles south of Schmidt Lane	3.06
42	FM 3177 South, at Texas Heritage Center sign	4.01
TC7	U.S. 183 frontage road, west bound, near intersection with U.S. 157, in Tarrant county, north of Arlington	3.36

* average PSI from 2 SDP runs on section

measured left wheelpath profile elevations from repeat runs of the SDP on Section 1. The correlation coefficient r between the measured profile elevations was determined to be 0.985 (as shown in Figure 1) with a standard error of the estimate of approximately 91 mils. Similarly, standard errors of estimate and correlation coefficients between measured profile elevations from repeat runs of the SDP on the other test sections were calculated. The results are presented in Table 2.

The correlation coefficients and standard errors of estimate shown in Table 2 were compared with the corresponding statistics calculated using Siometer and SDP profile elevations measured during a given run (Table 3). In general, the correlation coefficients between SDP and Siometer profiles taken during the same run are comparable with the correlation coefficients between corresponding SDP replicate runs. In addition, for six of the nine test sections (i.e., Sections 1, 7, 12, 40, 42, and TC7), the standard errors of estimate calculated using SDP and Siometer profiles are somewhat better than those calculated using SDP replicate profiles. Figures 2, 3, and 4 show the generally favorable agreement obtained between SDP and Siometer profiles for data measured from the left wheelpaths of Sections 1, 7, and 40, respectively.

An overall measure of the agreement between Siometer and SDP profile elevations was obtained by calculating the overall correlation coefficient between measured profile elevations from the two devices. Figure 5 shows a comparison of all measured profile elevations from the Siometer with the corresponding profile elevations from the SDP. The overall correlation coefficient between measured profiles taken during the same run from the two devices was determined to be 0.971, as shown in Figure 5. This is slightly greater than the overall correlation coefficient of 0.960 between profile

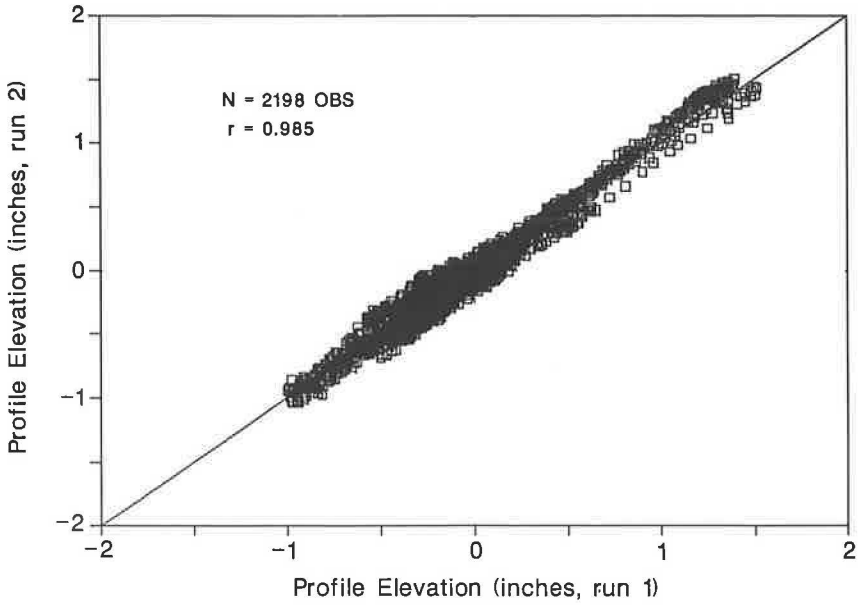

FIGURE 1 Comparison of left wheelpath profile elevations from repeat runs of the SDP on Section 1.

TABLE 2 CORRELATION COEFFICIENTS AND STANDARD ERRORS OF ESTIMATE BETWEEN REPEAT PROFILOMETER MEASUREMENTS

Section	Wheelpath	Correlation Coefficient	Standard Error of Estimate (mils)
1	left	0.985	91
1	right	0.967	125
4	left	0.983	94
4	right	0.976	122
7	left	0.936	70
7	right	0.936	70
12	left	0.890	92
12	right	0.866	99
21	left	0.987	73
21	right	0.952	121
31	left	0.973	55
31	right	0.980	80
40	left	0.961	117
40	right	0.969	137
42	left	0.956	67
42	right	0.935	80
TC7	left	0.833	168
TC7	right	0.869	168

elevations from repeat runs of the SDP. In addition, the overall standard error of the estimate between corresponding profile elevations from the Siometer and the SDP was calculated to be approximately 90 mils. The same statistic calculated using corresponding profile elevations from repeat SDP runs was determined to be approximately 107 mils.

The slightly lower correlation coefficient between profile elevations from repeat SDP runs and the higher standard error of the estimate obtained are largely attributed to variations in wheelpaths tracked between runs of the instrument. It is also likely that differences in starting times between repeat runs would have contributed to the slightly higher variation

TABLE 3 CORRELATION COEFFICIENTS AND STANDARD ERRORS OF ESTIMATE BETWEEN PROFILOMETER AND SIOMETER MEASUREMENTS TAKEN DURING THE SAME RUN

Section	Run Number	Wheelpath	Correlation Coefficient	Standard Error of Estimate (mils)
1	1	left	0.986	83
1	1	right	0.974	102
1	2	left	0.987	82
1	2	right	0.975	107
4	1	left	0.967	126
4	1	right	0.972	136
4	2	left	0.968	124
4	2	right	0.963	147
7	1	left	0.977	39
7	1	right	0.974	44
7	2	left	0.980	39
7	2	right	0.971	49
12	1	left	0.989	31
12	1	right	0.966	44
12	2	left	0.985	35
12	2	right	0.974	47
21	1	left	0.970	128
21	1	right	0.944	141
21	2	left	0.964	119
21	2	right	0.927	146
31	1	left	0.951	78
31	1	right	0.942	127
31	2	left	0.946	82
31	2	right	0.937	130
40	1	left	0.990	64
40	1	right	0.987	94
40	2	left	0.987	67
40	2	right	0.986	93
42	1	left	0.978	43
42	1	right	0.973	51
42	2	left	0.980	44
42	2	right	0.965	58
TC7	1	left	0.979	51
TC7	1	right	0.979	56
TC7	2	left	0.986	48
TC7	2	right	0.986	55

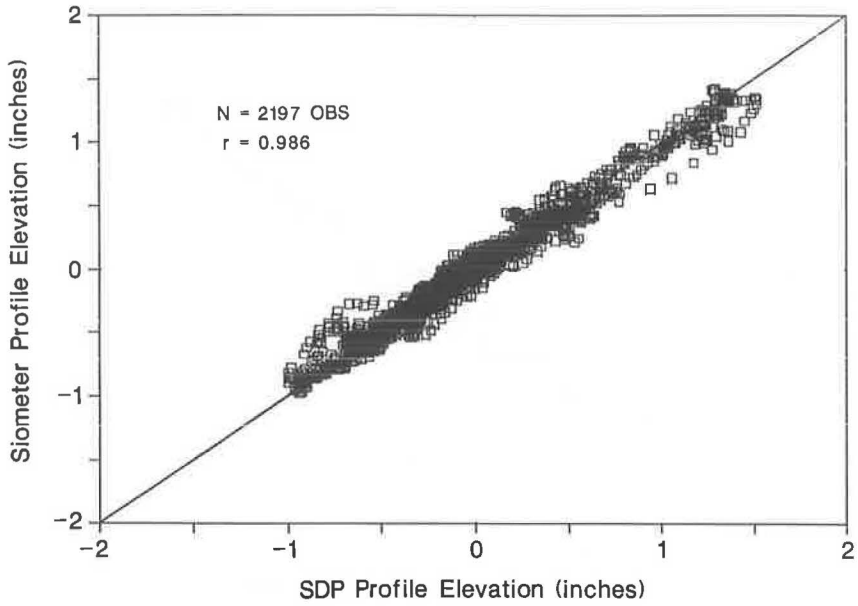

FIGURE 2 Comparison of profile elevations measured with the SDP and Siometer for the left wheelpath of Section 1 (Run 1).

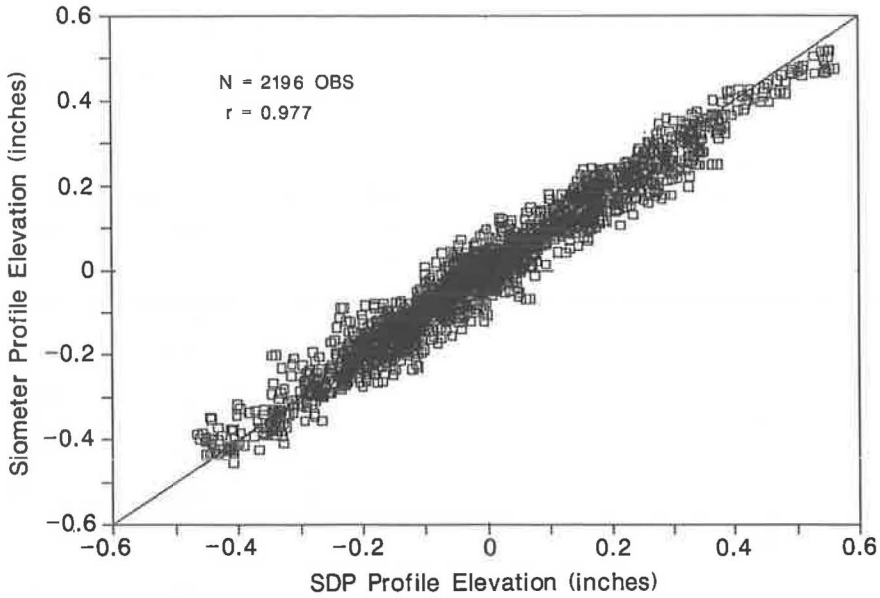

FIGURE 3 Comparison of profile elevations measured with the SDP and Siometer for the left wheelpath of Section 7 (Run 1).

between corresponding profile elevations from the SDP. However, to compensate for the effect of this factor, the SDP profiles from repeat runs were initially lined up before calculation of the statistics presented. This was done by means of cross-correlation analysis wherein profiles from repeat SDP runs were shifted relative to each other until a maximum cross correlation was obtained.

The close agreement between Siometer and SDP profiles taken under identical operating conditions lends credibility to the Siometer's approach for estimating pavement profiles. The essential element of this technique is the self-calibration scheme for parameterizing the statistical model of the vehicle on which the device is installed. The calibrated statistical model provides a way of separating the vehicle's contribution to the measured vertical accelerations from the input attributable to the road profile. In essence, the road profile is estimated from integration of the differences between measured accelerations and those predicted from the statistical model. For this study, the right and left sides of the SDP van were modeled differently so that the statistical models for the right and left wheelpaths were different.

In estimating pavement profiles with the Siometer, measured accelerations from the accelerometers mounted inside the SDP van were used in the computations. Thus, the

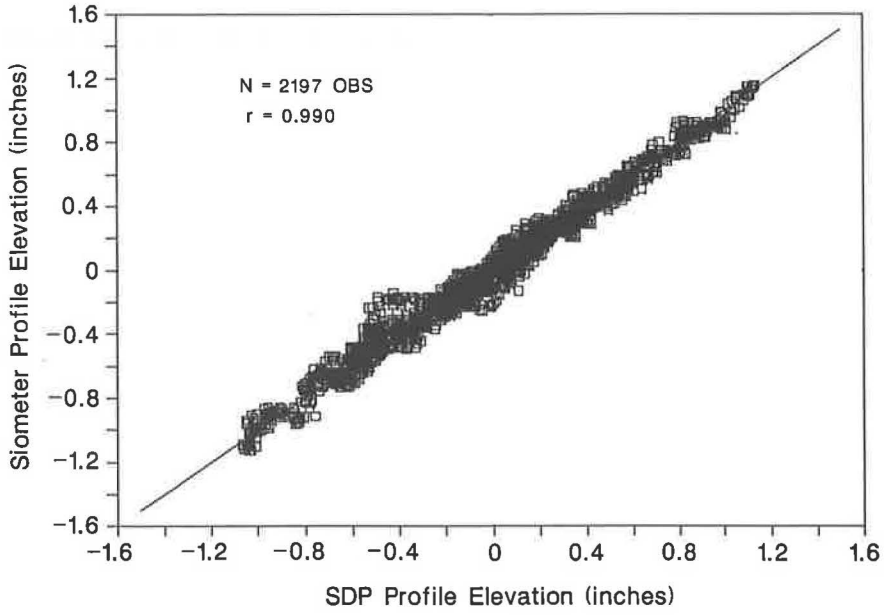

FIGURE 4 Comparison of profile elevations measured with the SDP and Siometer for the left wheelpath of Section 40 (Run 1).

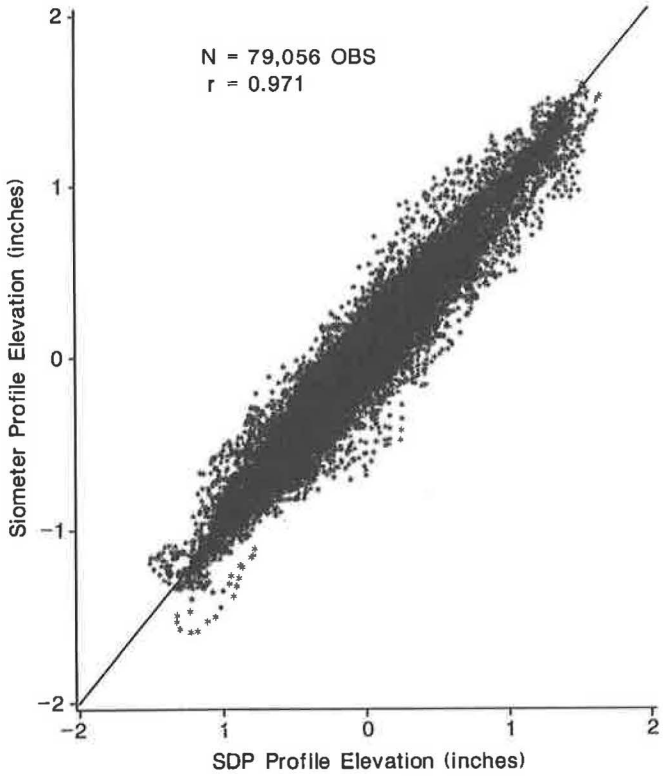

FIGURE 5 Comparison of Siometer profile elevations with SDP profile elevations.

operating conditions under which the SDP and Siometer profiles were taken were as close to being completely identical as can be arranged. In this way, the comparisons between the SDP and Siometer profiles clearly demonstrate the degree of capability of the Siometer's method of measuring pavement profiles. Judging from the results obtained, the Siometer's approach, based on measured vertical accelerations coupled with a statistical model of the vehicle, leads to profiles that are comparable to those obtained from the SDP, which is based on measured vertical accelerations and the use of noncontact probes (lasers) for determining the distance between the vehicle and the ground at any given time.

EVALUATION OF PROFILE POWER SPECTRA

The comparison of measured profiles between the SDP and the Siometer forms a basis for evaluating the applicability of the Siometer as a device for measuring pavement profiles. However, the evaluation should not stop here because differences in the frequency content of two pavement profiles may exist that are not readily apparent from a visual examination of the measured profiles. One can picture pavement profiles as consisting of the sum of a variety of waveforms of different frequencies and amplitudes. Waveforms of low frequencies or long wavelengths may be identifiable from a visual examination of a particular pavement profile. However, the high-frequency components will in all likelihood be masked because of the scales involved. Consequently, to obtain complete information on the frequency content of a particular pavement profile, its power spectrum must be evaluated by means of spectral analysis. A power spectrum is a graph of the frequency (as the abscissa) versus the power, which is the square of the amplitude of each frequency. In this way, the dominant frequencies or wavelengths within the profile can be identified. In addition, by comparing the characteristics of two profiles in the frequency domain, the similarity in the waveform composition of the two profiles can be evaluated.

A spectral analysis was conducted to determine the power spectra of the measured SDP and Siometer profile elevations. Figures 6 and 7 show the power spectra for the left wheelpath profiles of Sections 1 and 7, respectively. The higher the power at a given frequency, the more dominant are the waveforms of that particular frequency within a given pavement profile.

The results shown in Figures 6 and 7, which are typical of those that were obtained for all of the other profiles, illustrate the reasonable agreement between the power spectral densities of corresponding SDP and Siometer profile elevations. In these figures, the power spectral density (PSD) is expressed in dB units, defined herein as $10^*\log_{10}$ (amplitude squared per cycle per foot). In order to evaluate the agreement between SDP and Siometer power spectral densities, the overall correlation coefficient between the PSDs was determined. Figure 8 shows the PSDs of Siometer profile elevations and the corresponding PSDs of SDP profile elevations. Power spectral densities determined from SDP and Siometer profiles taken during the same run were compared.

The overall correlation coefficient between SDP and Siometer power spectral densities was determined to be 0.990. This value compares favorably with the overall correlation coefficient of 0.993 between the PSDs of profile elevations from repeat SDP runs.

In addition, a root-mean-square statistic that provides an overall measure of the match between the amplitudes of SDP and Siometer power spectra was calculated from the following expression:

$$\text{RMSD} = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - Y_i')^2}{n}} \tag{1}$$

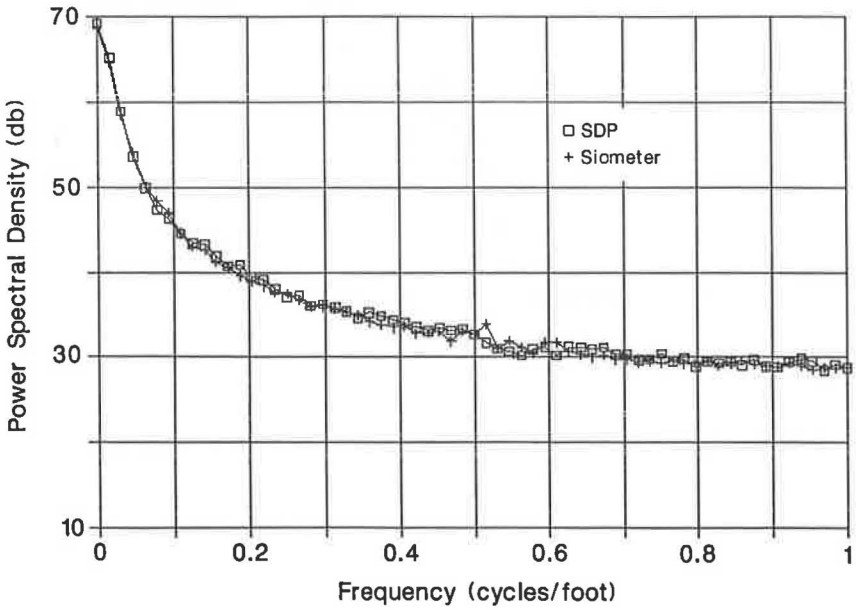

FIGURE 6 Power spectra of pavement profiles measured with the SDP and Siometer for the left wheelpath of Section 1 (Run 1).

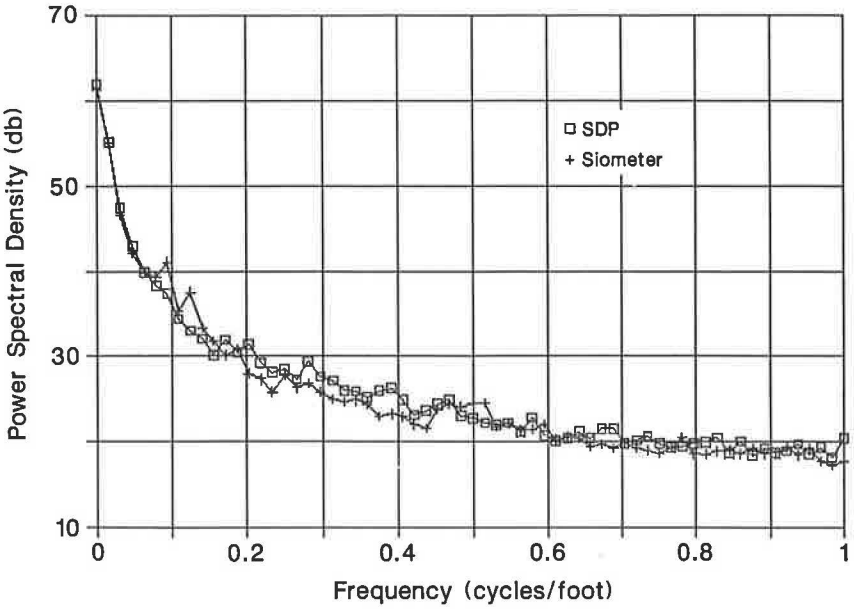

FIGURE 7 Power spectra of pavement profiles measured with the SDP and Siometer for the left wheelpath of Section 7 (Run 1).

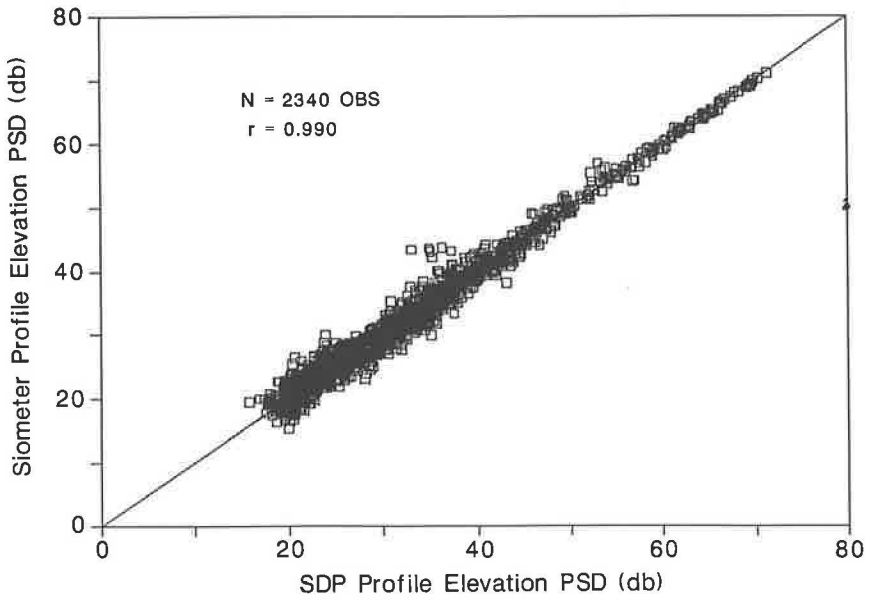

FIGURE 8 Comparison of power spectral densities of Siometer profile elevations with power spectral densities of SDP profile elevations.

where

RMSD = root-mean-square deviation, mils;
Y_i = SDP amplitude, mils;
Y_i' = Siometer amplitude, mils; and
n = number of observations.

Using Equation 1, the RMSD associated with the Siometer power spectra was determined to be 2.46 mils with 2,340 observations. A similar statistic calculated from the power spectra between repeat SDP runs was found to equal 3.87 mils with 1,170 observations. On the average, therefore, the amplitudes of the waveforms associated with Siometer profile elevations deviated from the amplitudes of the corresponding SDP waveforms by approximately 2.5 mils. Similarly, the amplitudes of the waveforms from repeat runs of the SDP differed, on the average, by about 4 mils. The higher RMSD obtained between amplitudes of power spectra from repeat SDP runs is again indicative of the effects of variations in wheelpaths tracked between runs of the instrument. Judging from the statistics presented, it is evident that the Siometer power spectra compare favorably with the corresponding SDP power spectra.

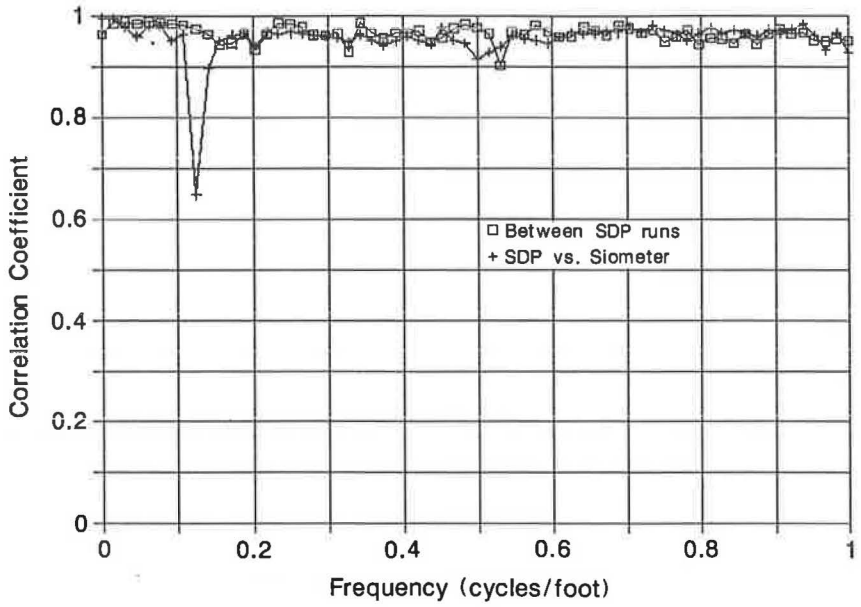

FIGURE 9 Correlation coefficients between roughness power spectral densities across the frequency domain.

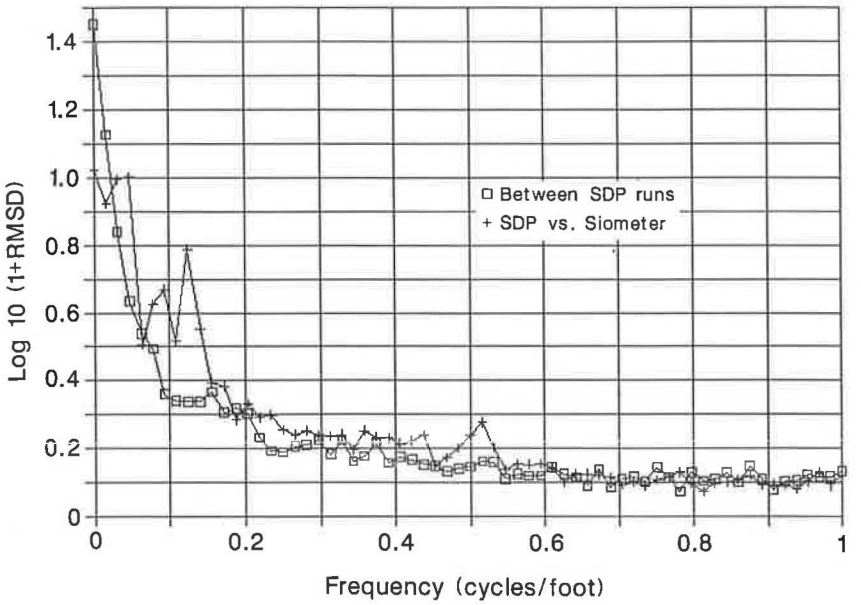

FIGURE 10 Root-mean-square deviations between amplitudes of profile spectra across the frequency domain.

However, while this may be true, the statistics presented only provide an overall measure of the agreement between SDP and Siometer profiles. It is also important to evaluate the agreement between profiles frequency by frequency. Consequently, the correlation coefficients and RMSD values were also compared frequency by frequency.

Figure 9 shows the correlation coefficients across the frequency domain, between PSD values from repeat SDP runs, and between PSD values from corresponding Siometer and SDP runs. Figure 10 shows the RMSD values. It is generally observed that the Siometer power spectra compare favorably with the SDP power spectra. However, at a frequency of 0.125 cycles/ft (about 3.7 Hz at 20 mph), the agreement is not as good compared with the other frequencies. At 0.125 cycles/ft, the correlation coefficient between Siometer and profilometer PSD values drops to about 0.65 as shown by Figure 9. This result suggests that a fundamental response frequency of the vehicle has not been removed and that a need exists for fine-tuning the procedure to parameterize the statistical model of the vehicle so that better agreement between the power spectra of Siometer and SDP profile elevations may be achieved within the entire frequency range.

EVALUATION OF LOAD PROFILES PREDICTED FROM SIOMETER ROAD PROFILES

Pavement surface roughness affects the vehicle dynamic loadings that are imparted to the pavement. Consequently, it is also appropriate to compare the load profiles associated with SDP and Siometer pavement profiles. After all, the dynamic loadings produced will affect pavement service life, and it is of value to know how the predicted dynamic load profiles differ from each other. This would provide another basis for judging the acceptability of the Siometer as a device for profile measurements.

A vehicle simulation program developed at Texas A&M University was used to predict the dynamic loadings produced by a given vehicle running over the measured SDP and Siometer profiles. The vehicle modeled was a tractor-semitrailer (3–S2) combination with a 12,000-lb steering axle load and a 34,000-lb tandem axle on each of the drive and trailer axles. The measured profiles for Sections 1 and 7 were used in the analysis. Two different vehicle speeds, 45 and 27 mph, were used in the simulation.

Figure 11 shows axle loads predicted using profiles from repeat SDP runs on Sections 1 and 7. In the simulation, dynamic axle loads were evaluated at 0.50-ft intervals along a given section for all five axles of the tractor-semitrailer combination. The overall correlation coefficient between axle loads associated with profiles from repeat SDP measurements was 0.990.

Similarly, dynamic axle loads predicted using Siometer profiles were compared with those predicted using corresponding SDP profiles. Figure 12 shows the axle loads evaluated using profiles from the two devices. The overall correlation coefficient between dynamic axle loads was 0.952. This value compared favorably with the overall correlation coefficient of 0.990 between axle loads associated with profiles from repeat SDP measurements. In addition, the root-mean-square deviations between dynamic axle loads predicted from SDP and Siometer profile elevations was 986 lb for 82,160 observations. This statistic was determined using Equation 1 with Y_i being the dynamic axle load predicted using SDP profile elevations and Y_i' the dynamic axle load associated with Siometer profiles. A similar statistic calculated between dynamic axle loads predicted using replicate SDP profiles was 446 lb for 41,080 observations. On the average, therefore, the dynamic axle loads associated with Siometer profiles differed from the corresponding axle loads associated with SDP profiles by 986 lb. This value is 8.2 percent of the nominal static axle load of 12,000 lb on the steering axle of the vehicle used in the simulation, and approximately 5.8 percent of the nominal static axle load of 17,000 lb on each axle of the drive and trailer tandems. The results therefore indicate reasonable agreement between SDP-based and Siometer-based dynamic axle loads.

The power spectra of the predicted dynamic loads were also evaluated to check the degree of similarity in the frequency content of the SDP and Siometer load profiles. Figures 13 and 14 show the load power spectral densities associated with the two devices for profile measurements made on Section 1. The load power spectral densities were determined using the predicted dynamic axle loads for the lead axles of the drive and trailer tandems, at a simulation speed of 45 mph. As seen from the figures, there is good agreement between the load PSD values associated with SDP and Siometer profiles.

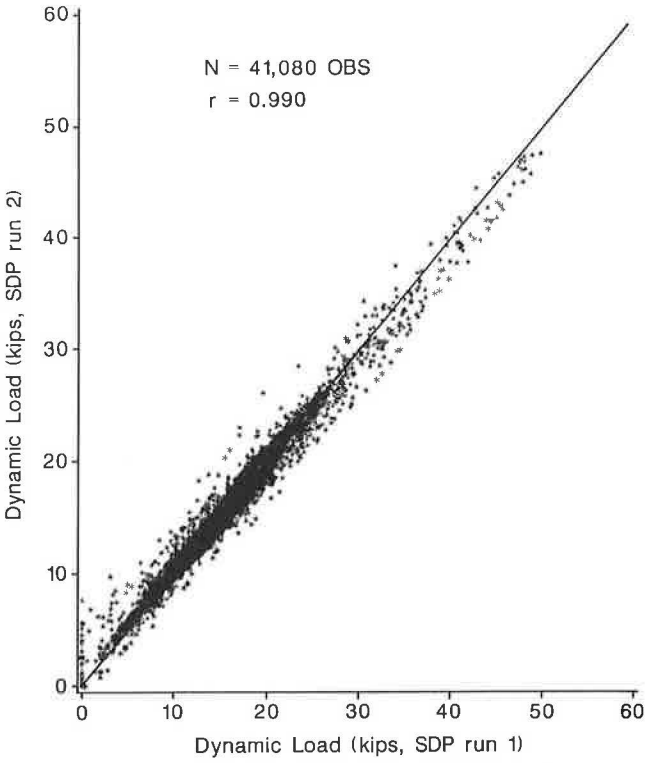

FIGURE 11 Comparison of dynamic axle loads predicted using replicate SDP profile measurements.

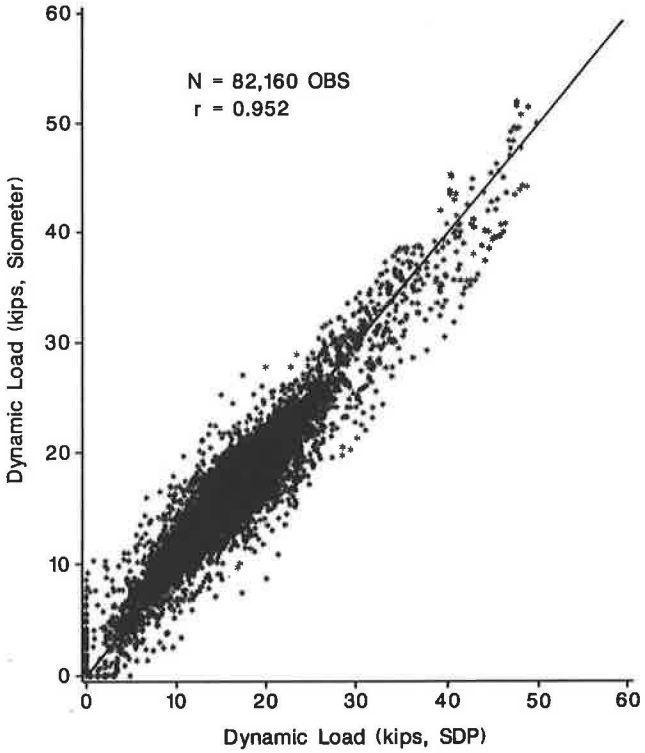

FIGURE 12 Comparison of dynamic axle loads predicted using Siometer profiles with dynamic axle loads predicted using SDP profiles.

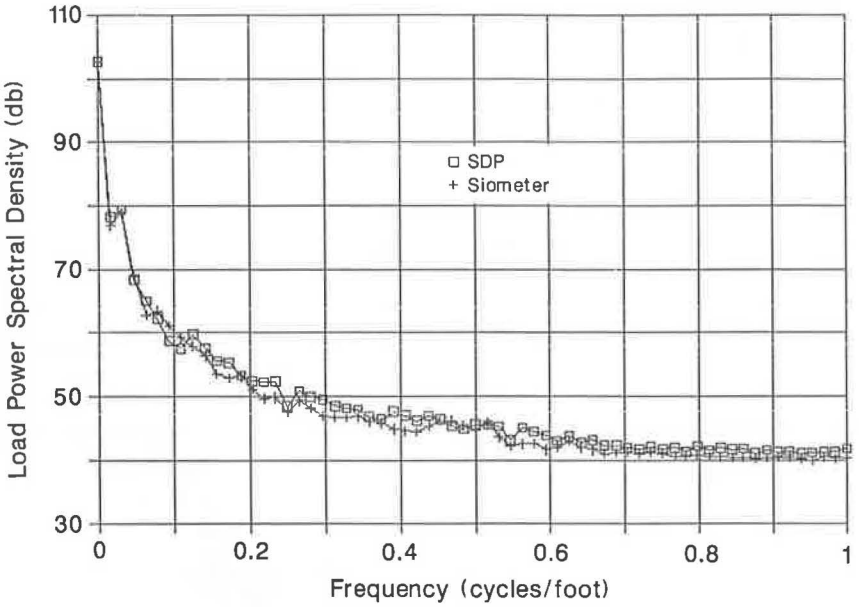

FIGURE 13 Power spectra of dynamic axle loads associated with profiles measured with the SDP and Siometer on Section 1 (Run 1), for the leading axle of the tractor drive tandem assembly.

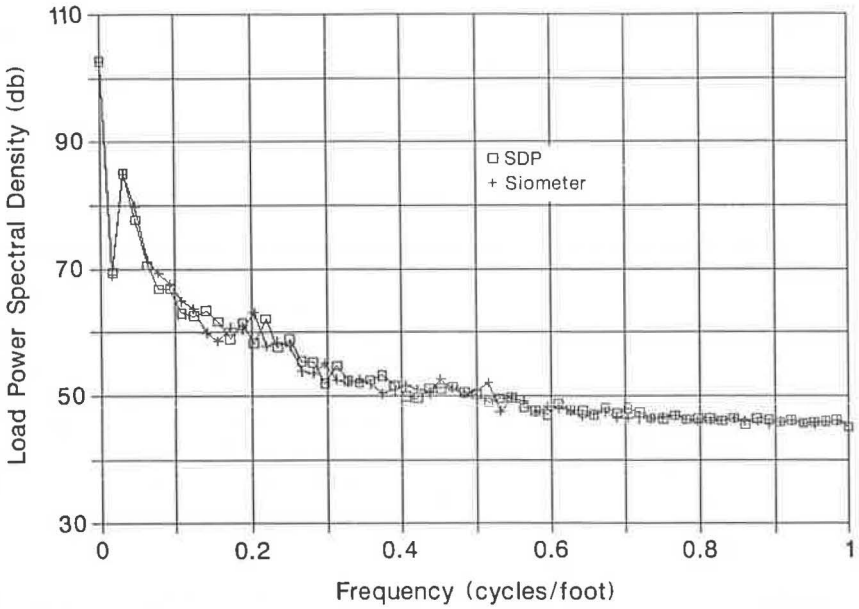

FIGURE 14 Power spectra of dynamic axle loads associated with profiles measured with the SDP and Siometer on Section 1 (Run 1), for the leading axle of the trailer tandem assembly.

In order to evaluate the agreement between SDP and Siometer load power spectral densities, the overall correlation coefficient between PSD values was determined. Figure 15 shows the load power spectral densities associated with SDP and Siometer profiles. An overall correlation coefficient of 0.982 was determined, as indicated in the figure. This value compares favorably with the overall correlation coefficient of 0.997 between power spectral densities associated with repeat SDP profile measurements.

In addition, the root-mean-square deviation between the amplitudes of SDP and Siometer load spectra was determined to be 29.58 lb for 2,600 observations. A similar statistic between the amplitudes of load spectra associated with repeat SDP profile measurements was found to equal 12.68 lb with 1,300 observations. Consequently, the amplitudes of the waveforms associated with the Siometer and SDP load power spectra differ on the average by about 30 lb. Similarly, the amplitudes of the waveforms associated with load power spectra from

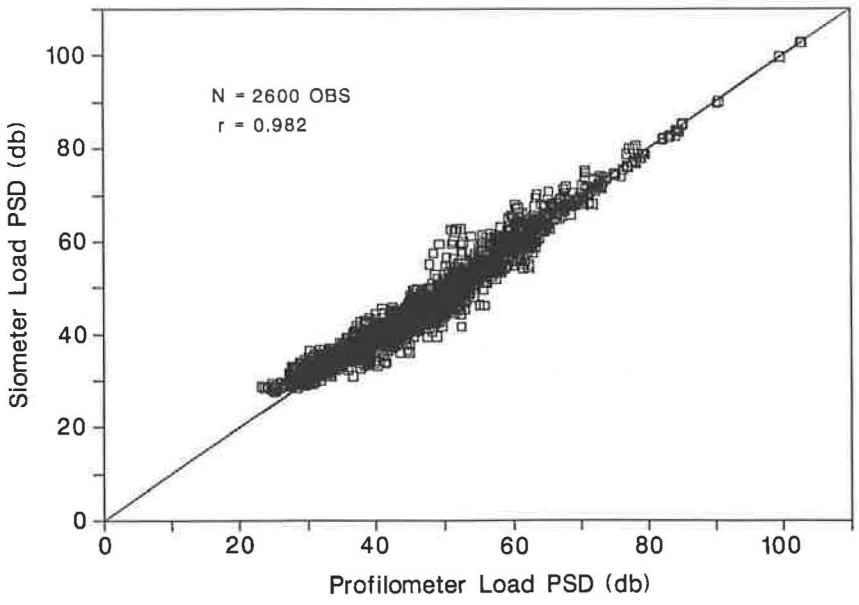

FIGURE 15 Comparison of load power spectral densities associated with Siometer and SDP profiles.

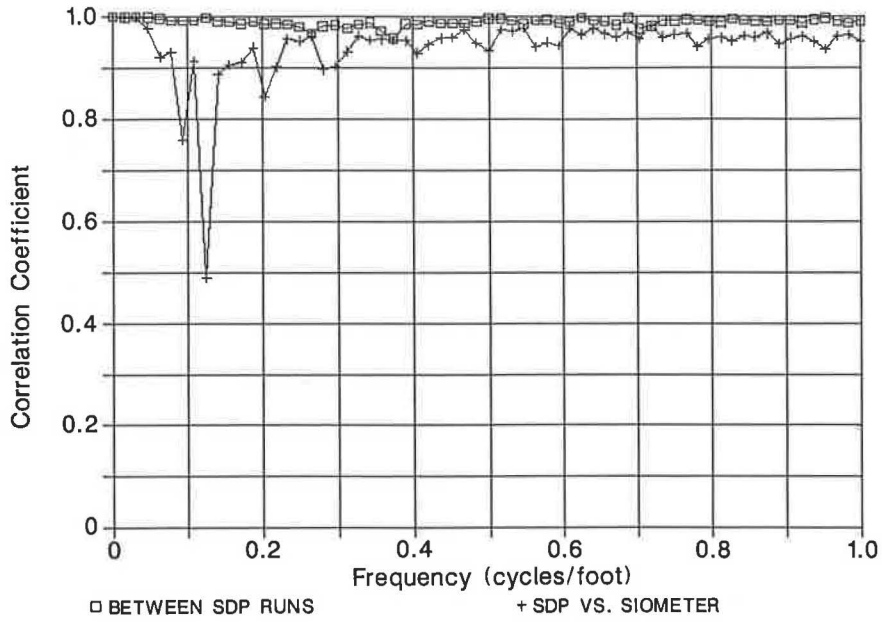

FIGURE 16 Correlation coefficients between load power spectral densities across the frequency domain.

replicate SDP profiles differ on the average by about 13 lb. These values suggest that the Siometer-based load power spectra matches fairly with the corresponding SDP-based load spectra.

The similarity in the load spectra associated with SDP and Siometer profile measurements was also evaluated frequency by frequency. Figure 16 shows the correlation coefficients between replicate load PSD values associated with repeat SDP runs and the correlation coefficients between load PSD values associated with Siometer and SDP roughness measurements. The trends observed are similar to those shown in Figure 9 of the correlation coefficients between power spectral densities of SDP and Siometer profile elevations across the frequency domain. The correlation coefficients across the frequency domain between SDP and Siometer load power spectral densities are generally acceptable. However, at a frequency of 0.125 cycles/ft, the correlation coefficient decreases to slightly less than 0.50. This decrease coincides with the decrease at this same frequency in the correlation coefficient between PSD values of SDP and Siometer profile elevations (see Figure 9). This result again points to a need for refining the vehicle modeling procedure on which the Siometer is based.

CONCLUSIONS

From the results of the evaluation conducted, the following findings are noted:

1. From an examination of the pavement profiles obtained from the same run, there is close agreement between SDP and Siometer profiles. This finding suggests that for practical purposes, the Siometer can show just as well as the SDP can, where the rough spots are on a particular stretch of highway.
2. From a comparison of predicted load profiles, Siometer profiles can reasonably be used in conjunction with a vehicle simulation program for identifying those portions of a given highway segment that are likely to be subjected to severe dynamic loadings.
3. From the spectral analysis of SDP and Siometer profile elevations, the Siometer power spectra compared favorably with the SDP power spectra. However, at a frequency of 0.125 cycles/ft, the correlation coefficient between power spectral densities of SDP and Siometer profile elevations decreased to approximately 0.65, indicating a need for fine tuning the vehicle modeling procedure on which the Siometer is based.
4. From the spectral analysis of dynamic axle loads associated with SDP and Siometer profiles, reasonable agreement between computed load PSD values was observed. The results also suggest that improving the correlation between power spectral densities of SDP and Siometer profile elevations at 0.125 cycles/ft will lead to better agreement between SDP and Siometer load PSD values within the entire frequency spectrum.

Overall, the results obtained are promising and show the potential of the Siometer as an economical, practical, and useful device for collecting profile data on a network-wide scale. Future measurements using the Siometer and the SDP are planned to get more data to further verify the acceptability of the Siometer as a device for profile measurements. Plans include measurements on portland cement pavement sections and reevaluation of the parameterization procedure for modeling the vehicle in the measurement process.

ACKNOWLEDGMENTS

This paper is based on results of a project funded by the Texas SDHPT.

REFERENCES

1. M. W. Sayers, T. D. Gillespie, and C. A. V. Queiroz. *The International Road Roughness Experiment—Establishing Correlation and a Calibration Standard for Measurements*. World Bank Technical Paper 45, The World Bank, Washington, D.C., 1986.
2. E. B. Spangler and W. J. Kelly. *GMR Road Profilometer—A Method for Measuring Road Profiles*. Research Publication GMR-452, Engineering Mechanics Department, General Motors Corporation, Detroit, Mich., Dec. 1964.
3. D. W. McKenzie, W. R. Hudson, and C. E. Lee. *The Use of Road Profile Statistics for Mays Meter Calibration*. Cooperative Research Program, Texas State Department of Highways and Public Transportation, Research Report 251-1, Austin, Tex., Feb. 1982.
4. R. S. Walker. *A Self-Calibrating Roughness Measuring Process*. Research Report 279-1, Texas State Department of Highways and Public Transportation, Austin, Tex., Aug. 1982.
5. R. S. Walker and T. P. Luat. *The Walker Roughness Device for Roughness Measurements*. Research Report 479-1F, The University of Texas at Arlington, July 1987.

The contents of this paper do not necessarily reflect the official views or policies of the Texas SDHPT or FHWA.

Publication of this paper sponsored by Committee on Surface Properties–Vehicle Interaction.