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Performance of the Mays Road Meter

Hugh J. Williamson, Yi Chin Hu, and B. Frank McCullough, Center for Highway Research, University of Texas at Austin

Serviceability index values obtained from the Mays meter and from the surface dynamics profilometer have been shown at times to differ by more than a point. A hypothesized explanation of these large discrepancies, based on the responses of the two machines to roughness with different ranges of wavelengths, is presented. Data from two sets of test sections are shown to be consistent with the hypotheses. The repeatability and day-to-day consistency of the Mays meter are also analyzed.

The Mays road meter (MRM) measures effect of the roughness of a road by summing the deflections of the rear axle of an automobile relative to the automobile body as the vehicle travels over the pavement. The mechanical details of the device, the measuring technique, and the calculation of a serviceability index (SI) from the MRM roughness measurement are discussed by Walker and Hudson (1).

The surface dynamics profilometer (SDP) is a more sophisticated device that can be used to obtain a measurement of road-surface elevation versus distance along the road in each wheel path. Obtaining an SI value for a road section as a function of the SDP measurements is also possible by using time-series analysis to compute characterizing measures of roughness and by using a regression model developed to relate roughness to serviceability.

Walker and Hudson discuss the calculation of SI values from measured profiles (2), and the measuring system is discussed by Walker, Roberts, and Hudson (3).

Periodically, an MRM must be recalibrated because of changes in the characteristics of the suspension system that affect the measurements (1). Significant changes in compression-rebound characteristics of shock absorbers or of stiffness of springs, for example, indicate the need for recalibration. The recalibration can be achieved by using SDP measurements because the performance of the SDP is very stable in time.

In addition to the shock absorber and spring characteristics, the following factors relating to the vehicle affect the MRM measurements: tire type and size, unsprung mass and sprung mass, including luggage and placement, mass of operating crew, and gasoline in tank. Sprung mass refers to the mass suspended by the springs. Because of hardware provisions within the SDP that are designed to remove the effects of the suspension system, the SDP measurements are affected drastically less by these factors than is the MRM (3).

An SDP measurement produces an approximate plot of the actual road profile (very long waves are removed by electronic filtering); however, the MRM produces only a single index that is believed to be related to the extent or severity of the roughness. Thus the two kinds of measurement are different in nature.

Because of the need for recalibration of MRMs and the much more detailed information provided by SDP measurements, the MRM will never completely replace the SDP and other similar systems. Because of its relatively low cost and simplicity of operation and maintenance, however, the MRM is more convenient for many purposes, particularly when only an overall indicator of roughness is needed and a large number of road sections are to be measured. Maintaining a fleet of MRMs to be used in different areas is feasible; however, owning a fleet of SDPs would involve a tremendous expense. Thus, there is considerable practical reason for interest in the adequacy of the MRM measurements.

Road meters similar to the Mays meter are used in many parts of the country. Although the results presented here apply only to the MRM, they are related in principle to the performance of other types of meters that are also based on the summation of rear-axle body deflections.

A set of roughness measurements were made on I-45 near Huntsville, Texas, to study the effects of swelling clay distress on the continuously reinforced concrete pavement (CRCP). Both the SDP and the MRM were operated on those sections, and large discrepancies between the SI values obtained from the two devices were observed.

DIFFERENCE BETWEEN SI VALUES FROM PROFILOMETER AND MAYS METER ON HUNTSVILLE SECTIONS

The CRCP test sections near Huntsville used in this study are sporadically affected by swelling clay and intermediate-length roughness; also, wavelengths of 6.1 to 24.4 m (20 to 80 ft) appear sporadically. These long waves are caused in part by the swelling clay. Patching has been performed continually to repair structural failures in the pavement.

Serviceability indexes were obtained from both the MRM and the SDP on successive 347.5-m (1140-ft) sections along this project; for convenience, the SI values from the MRM and the SDP are denoted SI_m and SI_p, respectively. The SI_m values range from only 3.2 to 3.5; the SI_p values, however, vary from 2.5 to 5.0. Figure 1 shows a plot of (SI_p - SI_m) versus SI_p. The linear nature of the plot is due to the small range of the SI_m values; (SI_p - SI_m) is nearly the same as (SI_p - a constant).

The differences between SI_m and SI_p cannot be explained in terms of random measurement errors alone. We hypothesized that the discrepancies could be explained in terms of the nature of the roughness measurements. The SDP is capable of measuring roughness with a wide range of wavelengths, and the SI model includes terms with wavelengths from approximately 2.6 to 26.2 m (8.6 to 86 ft) (2). The MRM, however, measures only that part of the roughness that causes the rear axle to deflect relative to the body of the automobile; although this is highly dependent on the suspension system of the particular automobile being used, one would suspect that the axle-body deflections would be more sensitive to short waves than to long waves.

Figure 2 shows conceptually the effects of different types of roughness on the SI_m and SI_p values. If, for example, the short waves are severe (have large amplitudes), the SI_m value will be low whether the long waves are severe (type d, Figure 2) or not (type b). The SI_p value, sensitive to both short and long waves, however, is much lower in type d than in type b. Thus, any time the long and short waves are greatly different in severity, the SI_m and SI_p values are likely not to agree. Comparing the severity of roughness with different wavelengths is a significant problem. Although a real road profile cannot easily be classified as one of these four hypothetical cases, they serve to illustrate the principle.

The mathematical methods most commonly used for analyzing highway roughness on the basis of wavelength are digital filtering (4, 5, 7) and power spectral analysis (2). These methods have been discussed in the literature and will not be treated in detail here. Because the computational speed of power spectral analysis is faster than that of digital filtering and because previous work (5) relating digital filtering output to serviceability was in a developmental stage when the Huntsville study began, power spectral analysis was employed.

Power spectral analysis is a method that can be used to compute amplitudes of surface undulations with different wavelengths. Figure 3 shows the amplitudes as a function of frequency (the reciprocal of wavelength) for two Huntsville sections for which SI_p = 5.0 and 2.5. The amplitudes are greater for the section with the lower SI_p value; however, this plot alone is not proof of the relative severity of the short as opposed to the long waves. There is clearly a need to convert the long waves, which have much larger amplitudes in general, and the short waves to a common scale to allow their comparison.

COMPARISON OF SEVERITY OF LONG AND SHORT ROUGHNESS WAVES

A scheme was devised to transform roughness amplitudes so that, for each of the wavelengths studied, derived roughness values fall within a range from 0 to 5, just as the SI values do. This approach involves the use of the power spectral values, which are directly related to the roughness amplitudes; the power spectral density corresponding to a given wavelength is the square of the roughness amplitude divided by a constant [the frequency bandwidth, 0.0381 cycle/m (0.0116 cycle/ft), in this case].

Walker and Hudson (2) averaged the power spectral values of 19 sections with present serviceability rating (PSR) values from 4.0 to 4.5 and of 10 sections with PSR values from 2.0 to 2.5 for a set of frequency bands. Thus, we have an estimate of an average power spectrum for a road with a PSR of 2.25 and for a road with a PSR of 4.25.

The results are given in Table 1 [in which a correction of a clerical error in Walker and Hudson's work (2) has been made in the power for a frequency of 0.0381 cycle/m (0.012 cycle/ft) for the low PSR values]. This table can be used to assess the severity of the roughness in different ranges of wavelengths. For example, if a road has a power of 0.0055 cm^2/cycle/m (0.0028 in^2/cycle/ft) at wavelengths 4.39 m (14.4 ft), this road can be said to be comparable to a road with a PSR of 4.25 with respect to the severity of the 4.39-m (14.4-ft) waves. Similarly, if the power is 0.0342 cm^2/cycle/m (0.0174 in^2/cycle/ft), then the road is comparable to a typical road with a 2.25 PSR with respect to 4.39-m (14.4-ft) waves.

Analysis of shorter wavelengths would be beneficial; because of high-frequency noise produced by the tape recorder originally used on the SDP, however, very short waves are not discussed by Shaw (2). The noise problem has subsequently been solved by installing a newer tape recorder. The transformation of a power value to a more easily interpreted quantity is achieved by the method described below.

Consider a wavelength of 4.39 m (14.4 ft). As indicated above, Table 1 gives two points on the SI versus power curve for this wavelength: SI $\approx$ 2.25 when the power is 0.0342/cm^2/cycle/m (0.0174 in^2/cycle/ft) and SI $\approx$ 4.25 when the power is 0.0056 cm^2/cycle/m (0.0028 in^2/cycle/ft). In addition, we assumed that SI = 5.0 if the power is 0 because 0 power is associated with a roughness amplitude of 0 at the wavelength in question. These three points on the SI versus power curve are joined by straight lines, as shown in Figure 4, to approximately the true function. Although this approach is somewhat crude because of the small number of points available on the power versus frequency curves, the interpolated SI values are much more easily interpreted than the power or amplitude values. Thus, the linear interpolation is adequate for the specific comparisons we wish to make.

Another condition that was imposed is that an additional point is added if negative interpolated SI values would otherwise have been obtained. Under this condition SI = 0 for the largest power observed in the sample of pavement sections used in the study. Figure 4 shows the piecewise linear function for a wavelength of 4.39 m (14.4 ft).

EXPLANATION OF MRM AND SDP DISCREPANCIES

Table 2 gives the interpolated SI values for each frequency for the sections shown as extreme points in Figure 1. The average interpolated SI, SI_m, and SI_p values are given below:

Wavelength (m)	Frequency (cycles/m)	Avg SI_p = 3.0 Avg SI_m = 3.4	Avg SI_p = 4.7 Avg SI_m = 3.2
8.8 to 26.4	0.039 to 0.115	2.3	4.1
2.6 to 3.3	0.302 to 0.381	3.6	4.2

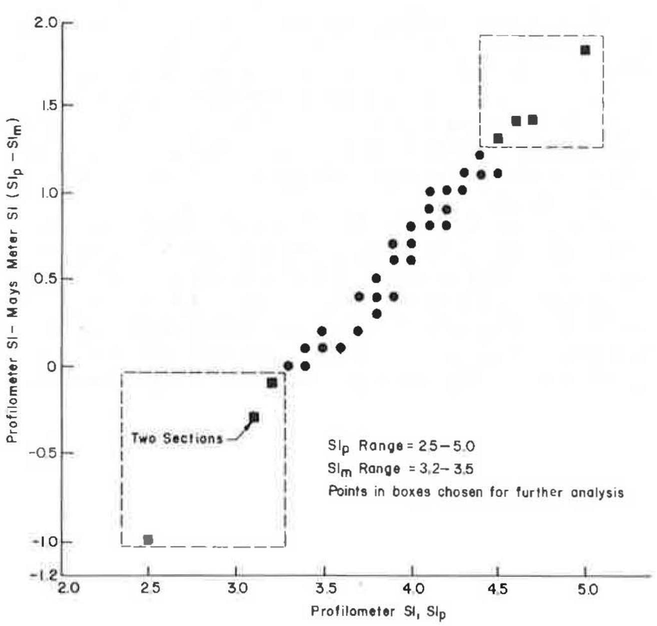
For the two sets of sections, the SI_m averages differ by only 0.2 (3.4 versus 3.2), and the SI_p differs by 1.7 (3.0 versus 4.7). The interpolated SI means for short wavelengths differ by a relatively small amount, 0.6. A statistical test revealed that this difference is not statistically significant at the 0.05 level. (A t-test for samples from populations with unequal variances was performed by using as data the individual section means over the three wavelengths (6, pp. 114-116).

A 1.8 difference, however, appears in the interpolated SI means for the long wavelengths. This difference is clearly statistically significant at the 0.05 level. The large variation in severity of long-wavelength roughness apparently affects the SI_p values but not the SI_m values.

Thus, the large difference in variation of SI_p values as opposed to SI_m values is explainable in terms of the responses of the different machines to roughness with different ranges of wavelengths. This explanation is in accordance with the conceptual hypotheses presented earlier about the reasons for differences between SI_m and SI_p values.

That there is not a perfect correlation between the SI_m values and the interpolated SI values for short wavelengths is probably due in part to the influence of shorter waves that were not analyzed because of the high-frequency, tape-recorder noise discussed above. The important point is that the interpolated SI means have sufficient physical meaning to shed light on the SI_m versus SI_p discrepancies.

Figure 1. (SI_p-SI_m) versus SI_p for Huntsville sections.



ROUGHNESS MEASUREMENTS ON A DIVERSE SET OF PAVEMENTS

Because of their special characteristics, the CRCP road sections discussed above are useful for illustrating certain differences between the SDP and the MRM. We felt,

Figure 2. Hypothetical road profiles and corresponding SIs.

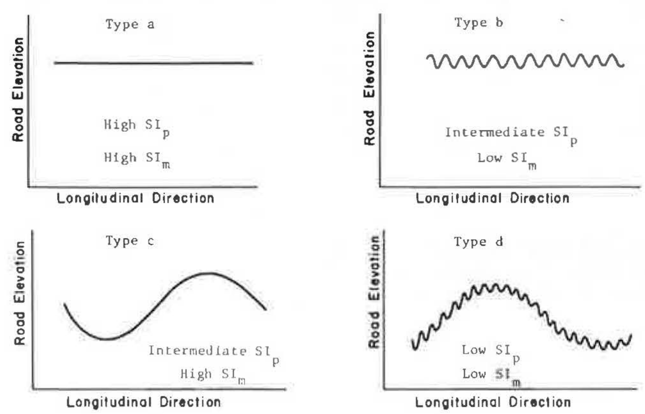
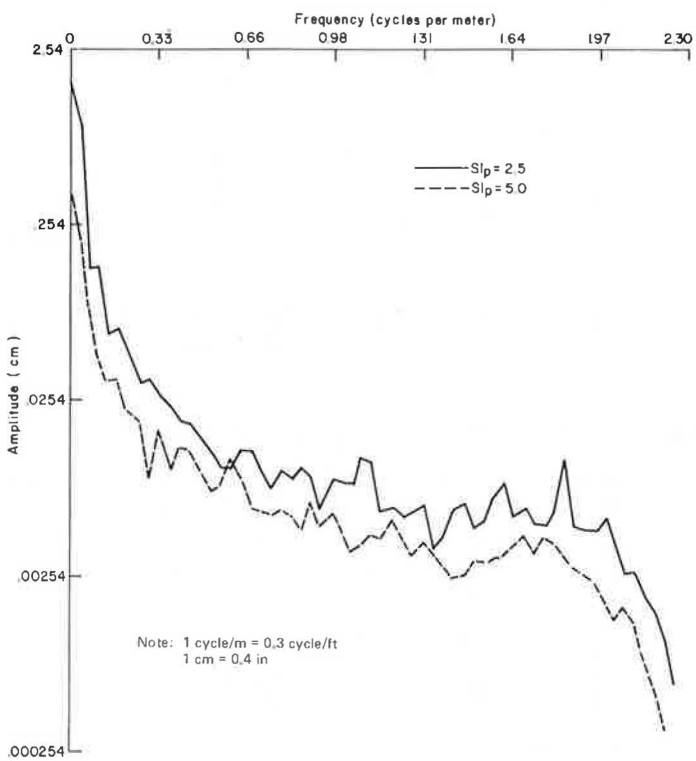


Figure 3. Amplitudes of roughness waves versus frequency.



however, that the results should be supplemented with a study of a more typical set of pavements with a wider range of SI_m values. The Austin test sections, which are used to calibrate the Mays meters used in Texas, were selected because they are a diverse set of pavements and because MRM and profilometer data are readily available for those sections.

Figure 5 shows a plot of (SI_p - SI_m) versus SI_p for the Austin test sections. For this set of test sections, the SI_m and SI_p do not have a consistent discrepancy, as they did for the Huntsville sections; when SI_p is low, for example, the difference (SI_p - SI_m) is neither consistently low nor consistently high. The inconsistency is at least partly due to the fact that the conversion for the MRM roughness measurement to SI is based on the SI_p values for those sections; in spite of that conversion, a consistent discrepancy would still be possible if the SI_p values reflected information that simply was not present in the MRM roughness measurements.

Table 1. Power spectrum statistics.

Frequency (cycles/m)	Wavelength (m/cycle)	Power Mean (cm^2/cycle/m)	
		2.0 ≤ PSR ≤ 2.5	4.0 ≤ PSR ≤ 4.5
0.039	26.4	9.4390	2.5456
0.076	13.2	0.4991	0.1023
0.115	8.8	0.1493	0.0313
0.151	6.6	0.0604	0.0149
0.190	5.3	0.0490	0.0087
0.226	4.4	0.0342	0.0056
0.266	3.8	0.0212	0.0049
0.302	3.3	0.0171	0.0043
0.341	2.9	0.0161	0.0035
0.381	2.6	0.0165	0.0033

Note: 1 cycle/m = 0.3 cycle/ft; 1 m = 3.3 ft; 1 cm^2 = 0.16 in^2.

The sections with moderate SI_p values, shown in the boxes in Figure 5, were selected for further analysis to explain differences in SI_m when SI_p varies within a very narrow range. The interpolated SI values are given in Table 3. Average values are given below (1 cycle/m = 0.3 cycle/ft, 1 m = 0.3 ft).

Wavelength (m)	Frequency (cycles/m)	Avg SI_p = 3.3 Avg SI_m = 2.6	Avg SI_p = 3.3 Avg SI_m = 3.7
8.8 to 26.4	0.039 to 0.115	3.5	3.6
2.6 to 3.3	0.302 to 0.381	3.8	4.4

The interpolated SI means for long wavelengths differ by only 0.1, which is practically and statistically insignificant. The interpolated SI values for short wavelengths differ by 0.6, however, and this difference is clearly statistically significant at the 0.05 level. (The section-to-section variation is smaller here than in the case in which a 0.6 difference was statistically insignificant for the Huntsville data.)

Thus, the larger variation in short-wavelength roughness has a stronger effect on the SI_m values than on the SI_p values. The wavelength analysis, then, is again consistent with the conceptual hypotheses stated earlier about SI_m and SI_p differences. The wavelength studies support, but do not constitute an absolute proof of, the hypothesis that SI_m and SI_p differences can be explained

Figure 4. Piecewise linear model for 4.39-m wavelength and 0.23-cycle/m frequency.

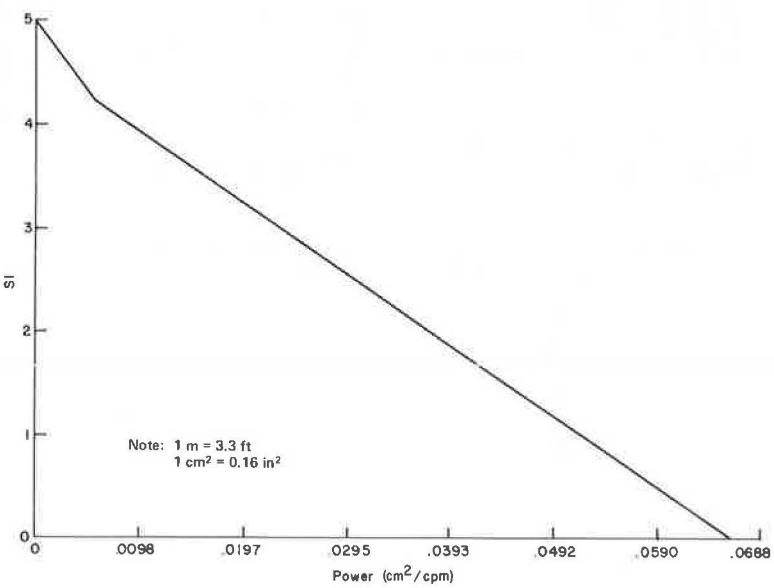


Table 2. Interpolated SI for each frequency band for Huntsville CRCP sections.

Wavelength (m)	Frequency (cycles/m)	Sections for Which $SI_p < SI_m$				Sections for Which $SI_p > SI_m$			
		SI_p = 2.5 SI_m = 3.5	SI_p = 3.1 SI_m = 3.4	SI_p = 3.1 SI_m = 3.4	SI_p = 3.2 SI_m = 3.3	SI_p = 4.5 SI_m = 3.2	SI_p = 4.6 SI_m = 3.2	SI_p = 4.7 SI_m = 3.3	SI_p = 5.0 SI_m = 3.2
26.4	0.039	1.5	3.1	4.4	1.8	4.1	4.8	4.8	4.8
13.2	0.076	3.3	0.0	3.2	2.3	3.5	4.2	4.0	4.1
8.8	0.115	1.6	1.6	2.6	1.9	3.4	3.6	3.7	4.3
6.6	0.151	2.7	2.0	1.8	2.1	4.4	4.0	3.8	4.2
5.3	0.190	2.0	0.0	3.0	3.0	4.3	4.1	3.6	3.9
4.4	0.226	2.6	1.3	3.8	3.2	4.4	4.1	3.6	4.1
3.8	0.266	3.1	2.0	4.0	3.4	4.4	3.9	3.0	4.2
3.3	0.302	2.2	4.2	3.8	3.5	3.9	4.1	3.8	4.6
2.9	0.341	3.3	3.7	4.1	3.9	4.2	4.2	3.8	4.1
2.6	0.381	3.7	2.9	4.1	4.2	4.1	4.3	4.1	4.7

Note: 1 cycle/m = 0.3 cycle/ft; 1 m = 3.3 ft.

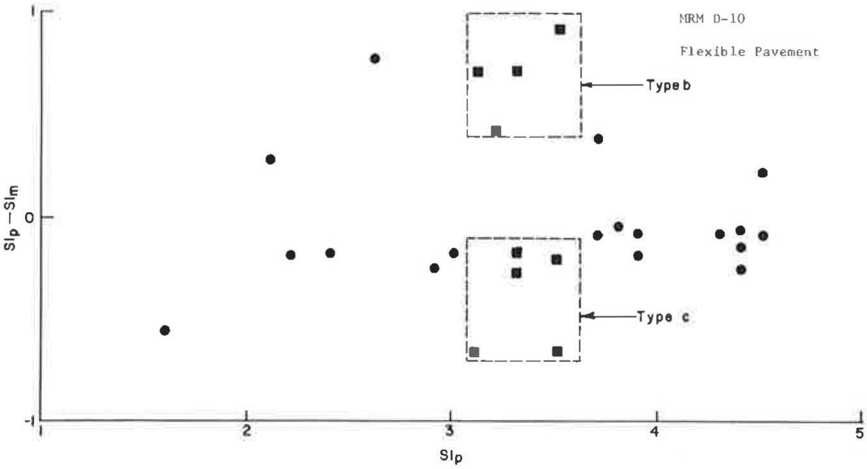


Figure 5. $(SI_p - SI_m)$ **versus** SI_p **for Austin sections.**

Table 3. Interpolated SI for each frequency band for Austin flexible test sections.

		Sections for Which $SI_p > SI_m$				Sections for Which $SI_p < SI_m$				
Wavelength (m)	Frequency (cycles/m)	SI_p = 3.50 SI_m = 2.59	SI_p = 3.30 SI_m = 2.60	SI_p = 3.10 SI_m = 2.40	SI_p = 3.20 SI_m = 2.78	SI_p = 3.30 SI_m = 3.48	SI_p = 3.50 SI_m = 3.71	SI_p = 3.30 SI_m = 3.57	SI_p = 3.50 SI_m = 4.15	SI_p = 3.10 SI_m = 3.75
26.4	0.039	3.8	2.5	3.8	2.0	2.0	4.0	1.9	3.7	4.5
13.2	0.076	4.2	3.1	3.7	3.9	3.7	4.2	3.4	4.2	3.7
8.8	0.115	3.7	3.5	3.4	4.1	4.2	4.2	3.0	4.1	2.7
6.6	0.151	3.0	3.8	3.2	4.3	4.2	4.5	3.4	4.3	2.8
5.3	0.190	4.1	4.2	4.1	4.2	4.4	4.3	4.4	4.6	4.4
4.4	0.226	4.0	4.0	3.6	4.1	4.2	4.2	4.2	4.2	4.5
3.8	0.266	4.1	4.1	3.5	3.8	4.2	4.3	4.2	4.6	4.4
3.3	0.302	3.6	4.1	3.6	3.3	4.4	4.3	4.2	4.2	4.5
2.9	0.341	3.9	4.1	3.6	3.7	4.4	4.3	4.2	4.3	4.5
2.6	0.381	3.9	4.1	4.0	3.6	4.7	4.6	4.4	4.8	4.6

Note: 1 cycle/m = 0.3 cycle/ft; 1 m = 3.3 ft.

in terms of different responses of the two machines to long and short roughness waves.

REPEATABILITY OF THE MAYS METER

The Austin test sections were also used to test the 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 one another. The sources of run-to-run measurement differences include variations in tire pressure and the inevitable small differences in the wheel paths traversed in successive runs. If sufficient distances are driven, the change in the weight of the gasoline in the tank can also have a significant effect. Gradual effects, such as changes in the shock absorbers and springs, would not be expected to cause run-to-run differences, although these gradual effects do cause long-term variations and necessitate recalibrations of the MRMs.

There were four repeated runs available for each section for each of two Mays meters. Under standard calibrating procedures, the MRMs are operated five times on each section, and the most deviate measurement is discarded. Thus, since the most extreme measurement for each section was not available, the variance estimates computed here are slightly low.

The conversion of each individual measurement to an SI value is possible. Standard statistical methods, then, can be used to compute the variance of the replication error. If SI_{ij}, j = 1, 2, 3, 4, are the SI values of the MRM corresponding to the ith section, and if $\overline{SI}_{i\cdot}$ is the mean of these four values, then

$$s^2 = \left[\sum_{i=1}^{n}\sum_{j=1}^{4}(SI_{ij} - \overline{SI}_{i.})^2\right]\Big/3n \qquad (1)$$

is an estimate of the error variance, where n is the number of sections used. Equation 1 is a standard one-way analysis of variance approach (6, 8).

The error variance for two MRMs used by the Texas State Department of Highways and Public Transportation is given below.

Mays Meter	Pooled Variance	d.f.	F
D-21	0.011 388	78	1.138
D-10	0.010 011	72	

An F-test reveals that, at the 5 percent level of confidence, one cannot conclude that either of the MRMs produces larger errors than the other. Since the error variances are both about 0.01, the standard deviation of the errors for both machines is about 0.1, which is only 2 percent of the scale, 0 to 5, for the SI values; thus, both machines are highly repeatable.

We suspected, because of their greater transverse surface irregularities, that roads with low SI values would induce greater measurement errors than would smoother roads. If this observation were true, more replicate measurements would be required on rough than on smooth roads to obtain average measurements with the same accuracy. The effect, however, was not observed in the Austin test-section data, but further study of this point would be beneficial.

CONSISTENCY OF THE TWO MAYS METERS USED

There has been much speculation about the consistency of the MRM measurements because these measurements are affected by some factors that are difficult to control [such as weight in the automobile (e.g., of the gasoline) and the tire pressure]. Because two MRMs were used in this study, comparison of their SI values is possible.

The runs with the two MRM machines were made a month apart, and a newer set of SI_p values was used to calibrate the second MRM. The SI_m values and the SI_p values for the sections whose SI_p values changed by 0.1 or less during the time interval involved are shown below.

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

Three points are important.

1. The SI_m values are in good agreement with the SI_p values. This agreement was expected because the SI_m values are computed by using calibrations developed from these SI_p values.
2. In 9 of 10 cases, the SI_m values are either both higher or both lower than the corresponding SI_p values, which indicates that the two MRMs are more consistent with each other than with the SDP. Thus, the systematic differences between the MRM and the SDP discussed above are consistent from Mays meter to Mays meter.
3. The fact that the pair of SI_m values for any of the 10 sections differs by no more than 0.26 indicates the excellent agreement between SI_m values obtained by operating different machines on different dates.

SUMMARY AND CONCLUSIONS

Devices such as the Mays meter will never replace more sophisticated instruments such as the SDP. The Mays meter is not stable in time and, hence, must be recalibrated periodically by using a time-stable device such as the SDP. In addition, the SDP provides much more detailed information about the roughness of a road and is therefore required for some applications. Such applications are discussed in other reports (2, 4, 5, 7). The less expensive Mays meters, however, provide adequate information in many cases if only a single overall measure of riding quality is needed and if the calibration is current.

The SI values for the same road section computed from SDP and from (calibrated) MRM roughness measurements sometimes desagree by over a point. The empirical evidence presented in this study indicates, however, that the differences are explainable by the fact that the Mays meter is sensitive primarily to short waves; however, the profilometer SI is based on roughness with a much wider range of wavelengths. In view of the observations made in the paragraphs below and the fact that the differences can be explained, this point does not indicate that measurements made with the Mays meter are invalid. The SI_m is best interpreted as a summarizing measure of short-wavelength roughness only. This type of measure is important because research results have indicated that ratings of riding qualtiy by human panels are highly correlated with short waves (5).

As a by-product of this study, the repeatability of the two Mays meters used and their day-to-day consistency were examined. The standard deviation of the measurement errors in replicate SI_m values for each of the two machines is about 0.1, which is only 2 percent of the range of the scale, 0 to 5, for SI. Thus, the repeatability is good for both machines.

Analysis of a small set of 10 sections measured on different dates with the two MRMs indicated high consistency between the two machines; the maximum SI_m difference for any section is 0.26. The tentative conclusion is that comparisons among SI measurements made under normal conditions with different MRMs can validly be made. This conclusion is consistent with the study of sources of MRM variations presented in (9).

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