Serviceability Index Base for Acceptance of Jointed Concrete Pavements

WILLIAM H. TEMPLE AND STEVEN L. CUMBAA

This paper describes the techniques and relationships developed to design a Serviceability Index (SI)–based measurement system for acceptance of jointed concrete pavement construction in Louisiana. Pavement roughness statistics obtained from Mays Ride Meter equipment, a Surface Dynamics Profilometer, and a Chloe Profilometer were regressed to establish an AASHO Road Test–based SI measurement system for concrete pavements with 20-foot joint spacings (SI JCP 20). A 1986 panel rating of 25 concrete pavements confirmed the validity of the model. Field testing of 50 newly constructed concrete pavement test sections provided a relationship between the SI JCP 20 model and profile statistics from rolling profilograph equipment and a 10-ft rolling straightedge. The research resulted in the development of a rational method of providing specification limits for profilograph equipment that relate to pavement rideability. Specification limits in terms of profile statistics are provided to indicate the quality of paving necessary to construct a jointed concrete pavement with a Serviceability Index of 4.5.

The constructed ride quality of jointed concrete pavements has been the subject of considerable research in Louisiana, generally resulting in the conclusion that roughness that is built into new pavements has increased as transverse joint spacings were reduced. In an attempt to reverse this trend, efforts have been made to establish a level of rideability that is considered acceptable and that is also reasonably constructable. A specification index that can be related to ride quality has been incorporated into a system for determining contractor compliance to the specification limits.

The research contained herein describes techniques and relationships used to accomplish:

- The selection of a specific level of AASHO Road Test based Serviceability Index (SI), which was set as a bench mark for ride acceptability on new jointed concrete pavements and
- The development of mathematical relationships to implement a specification procedure that is manageable under field conditions and utilizes relatively inexpensive but repeatable test equipment. Conversion relationships among a variety of roughness measuring devices were developed to facilitate field determination of the selected SI level for jointed concrete pavements with 20-ft transverse joint spacing. The devices include two different types of rolling profilograph, a Chloe profilometer, a Surface Dynamics Profilometer (General Motors), a Mays Ride Meter trailer system, and a 10-ft rolling straightedge.

Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, La. 70808.

SERVICEABILITY INDEX REQUIREMENTS

Paving specifications for jointed concrete in Louisiana have traditionally been expressed in terms of the percent of project length that exceeds a ⅛-in deviation in 10 feet as measured with a rolling straightedge. Surface tolerance specifications which have allowed up to 6 percent of the length of a project to be out of tolerance have typically resulted in "as constructed" Serviceability Index (SI) levels of between 3.0 and 4.0 for jointed concrete pavements. In an effort to increase the as-constructed SI level the surface tolerance specifications were amended and reduced from 6 percent to 0 percent, as measured with the rolling straightedge. At the same time, a decision was made to set a minimum acceptable SI level and to conduct research necessary to provide a limiting specification index that would produce this target SI.

At the request of the Federal Highway Administration, Louisiana DOTD adopted a target SI of 4.5 for construction of jointed concrete pavements. The basis for selecting this particular serviceability level was that it is an integral part of the assumptions in the current AASHTO design for rigid pavements. Jointed concrete pavements at the AASHO Road Test were constructed to a mean SI of 4.5, which, using equation 1, translates to a slope variance (SV) of approximately 2.2 (*1*).

$$SI = 5.41 - 1.80 \log (1 + \overline{SV}) \quad (1)$$

Flexible (non-jointed) pavement sections from the Road Test were constructed to a mean SI of 4.2, which, by equation 2, translates into an SV of approximately 1.7.

$$SI = 5.03 - 1.91 \log (1 + \overline{SV}) \quad (2)$$

A comparison of jointed concrete and flexible pavement smoothness using slope variance measurements indicates that the non-jointed sections at the Road Test contained less built-in roughness, since lower values of slope variance indicate a smoother pavement. A comparison by SI, however, seems to contradict the slope variance trend, since the jointed pavement was rated higher on a scale of 0 to 5, with 5 being perfectly smooth. This apparent contradiction is attributable to the panel service ratings (PSR) from which equations 1 and 2 were derived. The panel ratings confirm that at equal levels of serviceability rating, jointed-concrete pavements typically contain a greater measure of roughness. A dual method of relating roughness measurements obtained from jointed and non-jointed pavements is, therefore, indicated. This fact is graphically illustrated in figure 1.

Recognition of these trends is necessary for a contracting agency to correctly use AASHO-based SI to establish con-

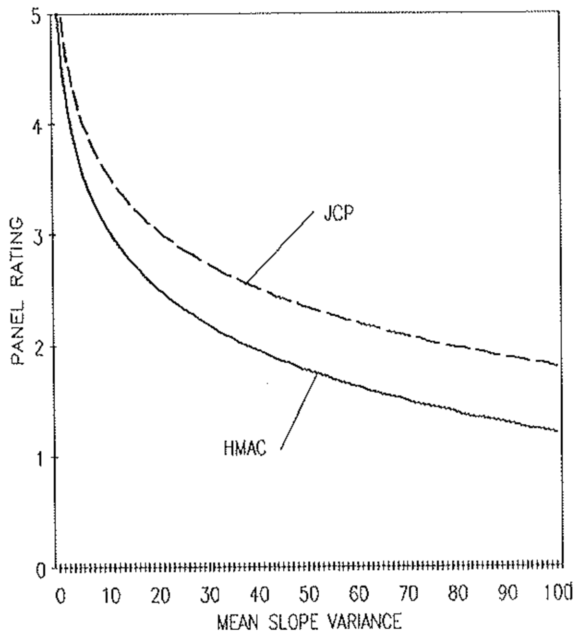

FIGURE 1 Panel rating versus slope variance for rigid and flexible pavements—AASHO Road Test.

struction limits for both jointed and non-jointed pavements to control ride quality.

SERVICEABILITY INDEX FROM FIELD MEASUREMENTS

Research studies since the early 1970s in Louisiana have involved a variety of rolling devices, each designed to provide an index of pavement roughness. The flow chart shown in figure 2 contains an overview of the procedures followed and the relationships between test equipment that lead to an AASHO-based SI measurement system for control of jointed-concrete paving.

A Mays Ride Meter (MRM) trailer system (with a suspension system modified according to Georgia DOT specifications to increase repeatability) provides a convenient means of estimating the SI of a pavement. Since 1975 MRM response measurements have been closely correlated to data from a Surface Dynamics Profilometer (SDP) at the Texas SDHPT using a procedure that relates SI to the inches-per-mile response measurement of the MRM (2). The SI equation indicated in figure 2 is a function of the vehicle ride characteristics of an individual vehicle (expressed as a and b) in conjunction with the MRM response index, inches-per-mile.

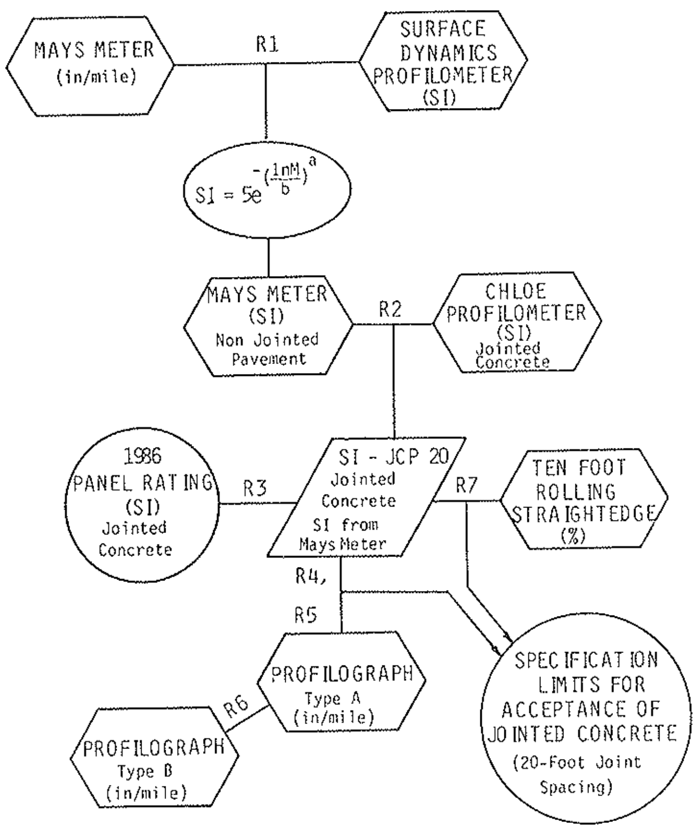

FIGURE 2 Regression relationships (R1–R7) for SI-based acceptance procedure using profilograph equipment.

The test sections used in the MRM-SDP correlation procedure have primarily been flexible, non-jointed pavements. The resulting relationships between the SI and inches-per-mile produced reasonable results when applied to flexible pavements in Louisiana; however, when applied to jointed concrete pavements, the SI predictions seem low. A review of pertinent literature confirmed the need for a dual rating system as previously indicated (*1*).

The Chloe Profilometer provided a mechanism for establishing a relationship between MRM-SDP SI for non-jointed pavements and a MRM-SI for concrete pavements with a 20-ft joint spacing, hereafter referred to as "SI JCP 20." In 1975, a field study of jointed-pavement roughness was initiated to develop the correlation. The results of the testing are presented in equation 3 and in figure 3.

$$[\text{MRM, SDP(SI)}] = 1.54\,(\text{Chloe, SI JCP 20}) - 2.82 \quad (3)$$

The regression analysis was performed in terms of SI values instead of using slope variance (SV) since the SVs of the two pavement types are not equal at a given SI level. Using this relationship, Louisiana DOT was able to implement a dual-rating system with correctly based SI relationships for field testing with MRM equipment, as depicted in figure 4.

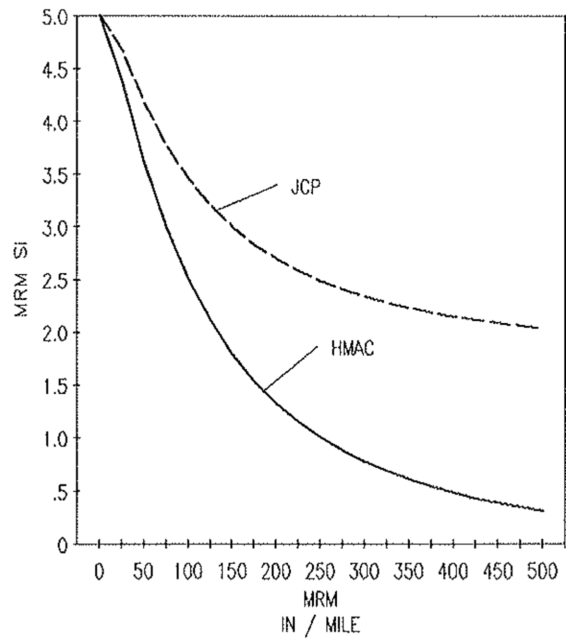

FIGURE 4 Mays ride meter (in/mile) versus SI for rigid and flexible pavements—Louisiana.

PANEL RATING VERIFICATION

In 1986, as a result of the Louisiana Transportation Research Center's (LTRC) participation in NCHRP 1-23(2), a panel rating of 25 jointed-concrete pavements was conducted using 36 raters. MRM tests were also conducted on the rating sections to provide LTRC with an opportunity to verify their SDP-Chloe based SI relationship.

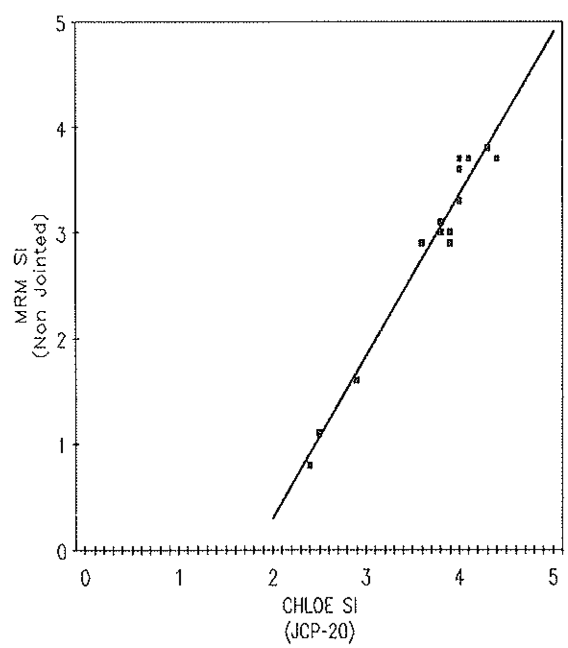

FIGURE 3 Mays ride meter/surface dynamics profilometer SI versus Chloe profilometer SI.

The results of the comparison, equation 4, provided a nearly 1:1 relationship between the 1986 panel rating and the "SI JCP 20" measurement as depicted in figure 5.

$$\text{SI JCP 20} = 0.94(\text{Rating}) + 0.19 \quad (4)$$

The SDP-SI (non-jointed) when applied to jointed pavement does not correspond to the 1986 panel rating data without the benefit of a correctly based panel relationship (Chloe) for jointed pavement as expressed in equation 3. This again illustrates the fact that panel raters respond differently to jointed-concrete and non-jointed pavements.

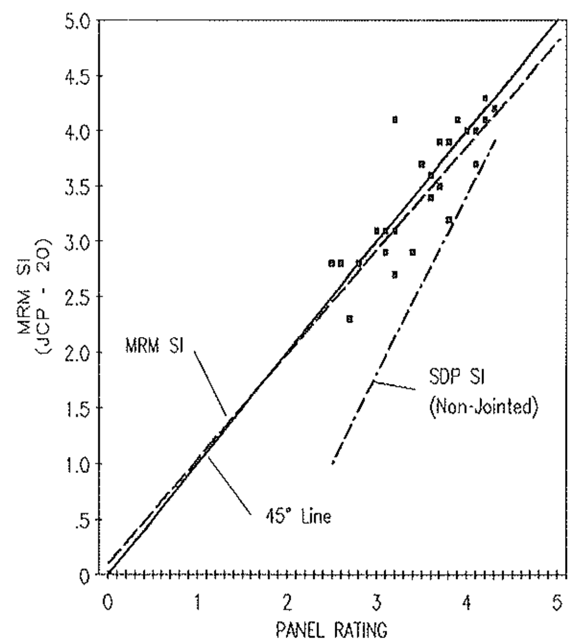

FIGURE 5 SI JCP 20 versus panel rating.

SPECIFICATION COMPLIANCE

Hand-operated rolling equipment can be used to provide construction personnel with verification of specification compliance in a timely manner. Vehicle response type measurement systems cannot be used as effectively to control a paving operation on a day-to-day basis, due to the physical limitations of heavy equipment being placed on concrete pavements that are gaining strength. The hand-operated devices must also provide reproducible results to instill in the users the level of confidence necessary for a successful testing program. Louisiana DOT has traditionally used only the 10-ft rolling straightedge for acceptance testing; however, because of calibration and reproducibility problems, the agency is now phasing in a rolling profilograph for concrete pavement acceptance.

10-FOOT ROLLING STRAIGHTEDGE

The rolling straightedge is a relatively inexpensive test device that can be used to control roughness during the paving process. Research testing with a carefully calibrated straightedge has resulted in a general correlation between "SI JCP 20" and the percentage of a test section that exceeds a ⅛-in deviation in 10 feet, expressed as equation 5 and depicted in figure 6.

$$\text{SI JCP } 20 = 2.0 + 2.5\, e^{(-0.10(\%))} \qquad (5)$$

Results of the testing indicate that in general a paving level of SI JCP 20 equivalent to 4.5 is possible only where there are zero deviations beyond ⅛-in in 10 feet. Surface tolerance specifications were amended in 1986 to require a "zero percent" specification in an attempt to implement this level of paving quality. Under the new specification, the consequence of non-compliance is surface grinding instead of a provision for contract payment reduction. The success of this approach

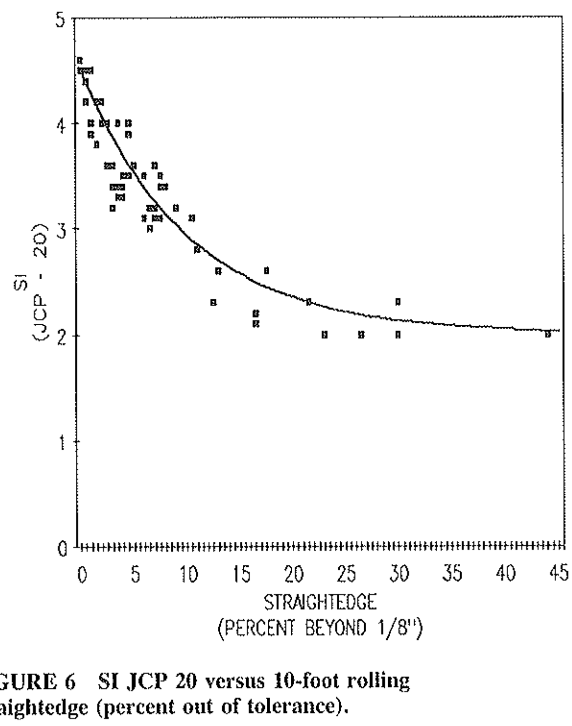

FIGURE 6 SI JCP 20 versus 10-foot rolling straightedge (percent out of tolerance).

in achieving the desired level of serviceability is currently being evaluated. In addition to calibration difficulties, it was observed that two rolling straightedge devices that were pulled together in the same wheelpath occasionally did not identify the same locations as needing grinding. Observations such as these quickly undermine confidence in a specification system that, at times, results in substantial quantities of ride correction on the part of the contractor.

ROLLING PROFILOGRAPH

Research underway using a 25-ft rolling profilograph (Ames model, designated Type A in figure 2) is producing improvements in terms of measurement repeatability and in the interpretation of exactly where ride correction is necessary. The profilograph is styled after the California profilograph in that the axes of the reference platform wheels are not uniformly spaced along the length of the device. Support is instead provided on each end by a group of wheels. Internal equipment calibration prior to testing is apparently not necessary for measurement reproducibility for this device. The pavement profile, which is graphically recorded, can be referenced to determine exactly where grinding is needed. Follow-up testing after grinding can be used to determine the need for additional reduction in the inches-per-mile statistic required for specification compliance.

Profile statistics (inches/mile) were calculated from the profile graphs on 50 test sections (0.2 miles in length) using both a 0.1-in and a 0.2-in blanking band for comparison. The profilograph roughness statistic accounts for only the magnitude of each bump or dip, whereas the rolling straightedge statistic accounts for the length of each deviation beyond a selected tolerance. For this reason profilograph testing on projects that contain many deviations of a small magnitude (such as 0.05 in) will result in a significantly lower summary statistic when using the 0.2-in band. Smoothness specification limits must, therefore, reflect the size of blanking band used to summarize the profile data.

A correlation between profilograph statistics and the SI JCP 20 reference data is depicted in figures 7 and 8 for the 0.1-in and 0.2-in bands, respectively. The equations for the two relationships are expressed as equations 6 and 7.

0.1-in band:

$$\text{in/mile} = 124.5 - 26.4 \qquad (6)$$

0.2-in band:

$$\text{in/mile} = -1.9 + 8997.4\, e^{(-1.76(\text{SI}))} \qquad (7)$$

The results indicate that to achieve an SI of 4.5, approximate specification limits should be 6 in/mi using a 0.1-in band and 1 in/mi using a 0.2-in band. The 12-in/mi specification limit currently used by several contracting agencies is likely to produce a SI level less than 4.0 using the 0.2-in blanking band relationship.

Another style of profilograph (Rainhart, designated Type B in figure 2) was used to test 18 sections. The device contains 12 reference platform wheels with axes evenly spaced along its length. The two different types of profilograph consistently agreed on the location of bumps and dips, although not to the same magnitude of surface deviation, as indicated by the relationship in equation 8 and figure 9. Specification limits

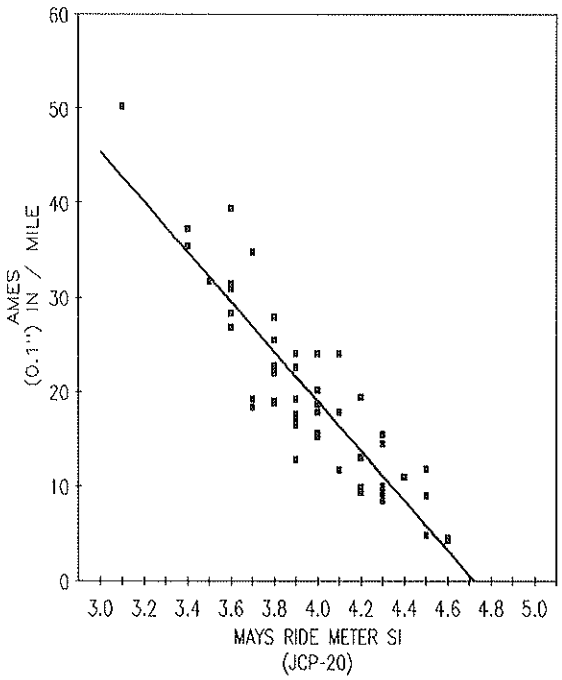

FIGURE 7 Ames Profilograph (in/mile) with 0.1-inch blanking band versus SI JCP 20.

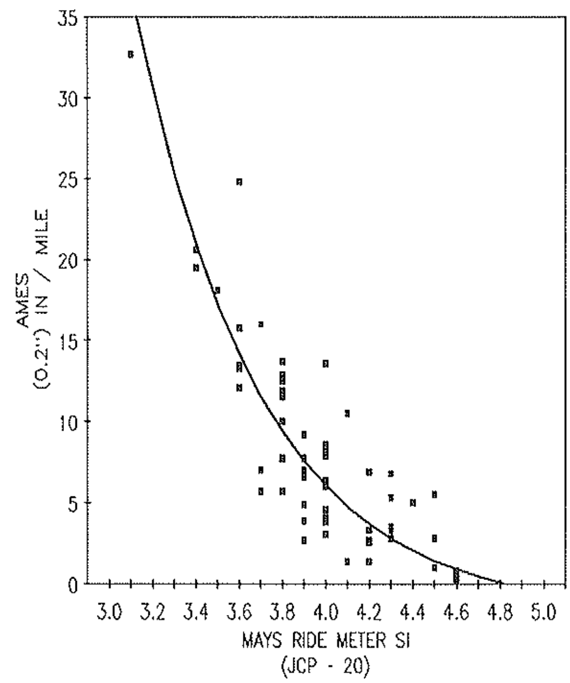

FIGURE 8 Ames Profilograph (in/mile) with 0.2-inch blanking band versus SI JCP 20.

expressed in inches-per-mile must recognize the proper SI equivalency associated with a particular style of profilograph used to conduct field tests.

$$\text{in/mi, Type B} = \frac{(\text{in/mile, Type A}) - 4.18}{1.04}$$

SIGNIFICANCE OF REGRESSION EQUATIONS

Statistical tables indicate that the six regression relationships developed in the study each contain correlation coefficients that are significant at all levels. Variance in test data is expressed as R^2 (coefficient of determination) and s^2 (residual mean square) in table 1.

ADDITIONAL RESEARCH

LTRC is using the rolling profilograph to evaluate roughness in newly constructed jointed concrete pavements to determine among other things:

- The magnitude and frequency of surface deviations typically occurring in paving projects,
- The location of surface deviations with respect to transverse joints created by sawing or by using inserts, and
- The success of grinding as a ride correction technique.

Early indications are that using the 10-ft rolling straightedge as an identifier for grinding does not result in significant improvements in SI measured after ride correction. Additionally, it appears that profilograph and rolling straightedge equipment often do not identify the same locations as needing ride correction.

CONCLUSIONS

1. Rating panels react differently to jointed concrete and non-jointed flexible pavements at equivalent levels of measured roughness; therefore, models used to predict the pave-

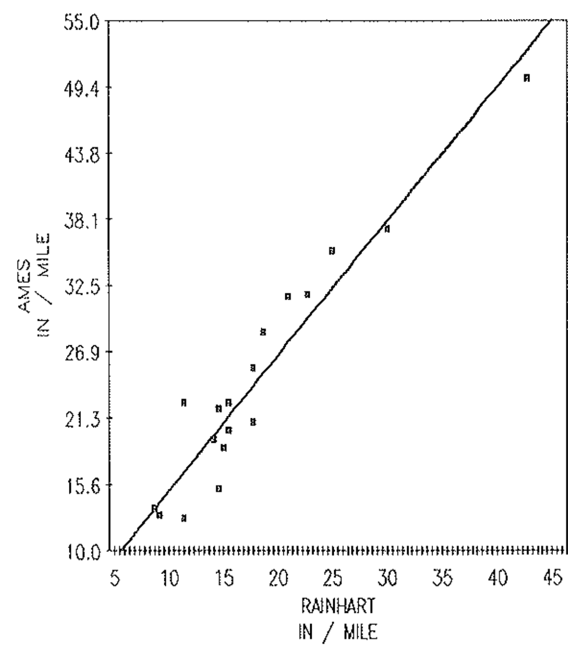

FIGURE 9 Rainhart Profilograph (in/mile) versus Ames Profilograph (in/mile).

TABLE 1 REGRESSION RELATIONSHIPS

REGRESSION MODELS Referenced in Figure 2	VARIABLES				STATISTICS	
	DEPENDENT		INDEPENDENT		R^2	s^2
R1	SI	Surface Dynamics Profilometer (Non Jointed)	In/Mile	Mays Meter (Non Jointed)	0.99	0.32
R2	SI	Mays Meter (Non Jointed)	SI	Chloe Profilometer (JCP 20*)	0.96	0.04
R3	SI	Mays Meter (JCP 20)	SI	Panel Rating (JCP 20)	0.73	0.10
R4	In/Mile	Profilograph - Type A 0.1" blanking band	SI	Mays Meter (JCP 20)	0.79	17.95
R5	In/Mile	Profilograph - Type A 0.2" blanking band	SI	Mays Meter (JCP 20)	0.75	3.03
R6	In/Mile	Profilograph - Type B 0.1" blanking	In/Mile	Profilograph - Type A 0.1" blanking band	0.91	9.43
R7	SI	Mays Meter (JCP 20)	Percent Out	10-Foot Rolling Straight Edge	0.89	0.05

Profilograph
Type A - California Style (Ames)
Type B - Multi-Wheel/Multi-Axle (Rainhart)

*Jointed Concrete with 20-foot Spacing

ment Serviceability Index using the output from response type roughness devices and profilographs need to reflect this fact.

2. Profile statistics from hand-operated profilograph equipment can be related to a selected level of SI for development of specification limits. A contracting agency can use this approach to develop a rational method of specifying a level of ride quality measured with profilograph equipment.

3. Roadway profile measurements obtained from two different styles of profilograph indicate that the devices agree on the location of surface deviations but do not agree on the magnitude of the deviations. The 10-ft rolling straightedge often did not agree with the two profilographs on either the location or the magnitude of surface deviations.

4. A Serviceability Index measurement procedure for jointed-concrete pavements developed from field tests using the Mays Ride Meter, the Surface Dynamics Profilometer, and the Chloe Profilometer was verified in 1986 by a 36-member panel rating.

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