18. P.G. Jordan and J.C. Young. Developments in the Calibration and Use of the Bump Integrater. Journal of the Institute of Highway Engineers, No. 4, April 1981.
19. R. Robinson, et al. A Road Transport Investment Model for Developing Countries. Department of the Environment, Department of Transport, Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Rept. LR 674, 1975.

Notice: Views expressed in this paper are not necessarily those of the TRRL Department of the Environment or the Department of Transport.

Use of Response-Type Roughness Meters for Pavement Smoothness Acceptance in Georgia

WOUTER GULDEN, JERRY STONE, AND DENNIS RICHARDSON

The use of response-type, road-roughness-measuring systems as part of surface tolerance specifications is attracting increasing interest among highway agencies as a rapid, inexpensive means of measuring the smoothness of roads during and after construction. Problems such as calibration, vehicle maintenance, and the repeatability of test results must be taken into account and resolved or minimized when these roughness-measuring systems are used for acceptance or rejection of projects for smoothness. The Georgia Department of Transportation has been using road meters in its specifications since 1972 for acceptance of projects and since 1979 for both rejection and acceptance. The evolution of the road-roughness-measuring program in Georgia, the calibration and operating procedures, the current smoothness specifications, and the use of Mays meter data during construction are described.

The surface smoothness testing program of the Georgia Department of Transportation (DOT) has evolved over the years from the rolling straightedge to trailer-mounted Mays ride meters and from testing for information purposes only to project construction control and acceptance. Many changes in equipment and procedures were made during this evolution to enhance the program and to ensure acceptance of the test results by contractors and project engineers alike.

Before 1966 the rolling straightedge was used to measure and control pavement roughness. Realizing the shortcomings of the straightedge in relating surface profile deviations to ridability, the Georgia DOT began to experiment with the CHLOE profilometer, but it soon became obvious that this device was too slow to be used in a large-scale program.

In 1968 Georgia began using the Portland Cement Association (PCA) road meter on a limited basis to check the roughness of various Interstate projects and some other selected paving projects. The road meter was installed in a carry-all type of vehicle, although it was designed to be installed in a standard-sized car.

The road-meter program was expanded in 1972 with the purchase of a PCA meter for each of the seven highway districts in Georgia so that each paving project could be monitored during construction. Each project was also measured for ridability before construction so that it would be possible to determine the amount of improvement in ridability after resurfacing.

The test results had previously been provided to contractors and project engineers so that they could become familiar with roughness testing and the results that were being obtained. In 1972 the Georgia DOT began using the PCA meter in lieu of the straightedge for acceptance of pavement smoothness on construction projects. If a project met the PCA meter specification it was accepted without further testing, but if it failed to meet these ridability requirements the failing sections were then retested with the rolling straightedge. The PCA meter was therefore used only as an acceptance tool, and any penalties were assessed based on rolling-straightedge results.

The carry-all vehicles were replaced during the next few years, and each district purchased replacement vehicles independently. By 1976 the meters were mounted in a variety of vehicle types, such as suburbans, station wagons, and cars of various sizes and makes. During this time the PCA meter was still used for acceptance testing only, and variations in road profile response from the various vehicles were unimportant to the contractor because penalties were still being assessed based on straightedge results.

Monitoring of the results obtained with the PCA meter and the rolling straightedge showed no consistent correlation between these two devices. Frequently, a section that failed the PCA meter requirements would be assessed no penalties based on the rolling-straightedge method. Sections determined to be acceptable by the road meter were sometimes found to have failed the straightedge requirements. It was obvious that the two devices did not give compatible results on all types of roads and roughness levels.

In 1975 the decision was made to standardize the PCA meter so that it could eventually be used for construction control and entirely replace the rolling straightedge. A testing program was conducted to compare PCA meter results obtained by various vehicles. The station wagon was chosen as a standard test vehicle and a fleet of station wagons was purchased.

Several other changes were made at the same time in an effort to standardize the equipment and upgrade the reliability of the testing program. An automatic null system was added to all PCA meters, radial tires were used on all test vehicles, and tires were trued and balanced as necessary. A lever arm system was developed so that individual units could be mechanically adjusted to produce comparable readings. A precise speed-deviation meter was used so that testing speed could be maintained to ±1 mph. A spare bank of counters was added to allow for continuous testing, and cruise control was used to maintain a uniform testing speed.

In addition, an operator's manual was written and all operators were given a training course in the use of the PCA meter. The manual contained detailed operating instructions; standard specifications for factors such as speed, tire pressure, and shocks; and detailed procedures for maintaining calibration. Calibration test sections were also established for each district.

By 1979 the roughness-testing program had progressed to the point where the PCA meter was used for construction control. Pavement sections that did not meet the roughness specifications after construction or resurfacing had to be corrected by the contractor at no cost to the state DOT.

By this time it was becoming apparent that it would be difficult to maintain a standardized vehicle over a period of years. Problems occurred when the road-meter vehicles had to be replaced because of excessive mileage and wear and tear on the suspension system. The response of the vehicle to road roughness is related to vehicle suspension and damping characteristics. It is important, therefore, that replacement vehicles have the same basic weight, wheelbase, and suspension characteristics as the original vehicle.

Vehicles that are currently being manufactured are increasingly smaller and lighter in weight. This means that existing standards for defining the roughness of a road would be altered every time the road-meter vehicles needed replacing. To eliminate this problem it was decided to mount the roughness-measuring equipment in a standardized test trailer.

A drawback of the PCA meter system was that it provided the roughness level for a section but could not distinguish where in a section the roughness was located. Such data are important because the specifications require correction of failing sections and each section tested is normally 1 mile long. The PCA meter does not indicate whether the entire section is rough or excessive roughness comes from specific areas within the tested section. Therefore, it was decided to change the testing equipment from a vehicle-mounted PCA meter to a trailer-mounted Mays meter.

In 1979 the first trailer-mounted Mays meter was acquired for experimental purposes. Based on the favorable results obtained with the first unit, trailers were purchased for each district in 1980 and the Mays meter system was put into full operation on January 1, 1981. During the transition period, projects contracted that used the PCA meter specifications were accepted based on Mays meter results. If a section failed, retests were conducted with the PCA meter in order to be fair to the contractor. All projects that were contracted after January 1, 1981, were tested with the Mays meter only.

PRESENT ROUGHNESS-TESTING PROGRAM AND EQUIPMENT

The trailer-mounted Mays meter is used in each highway district in Georgia to measure the pavement roughness of all projects before, during, and after construction. Each district is responsible for scheduling, making roughness measurements, and calibrating the trailers a minimum of every 2 weeks. The central office has overall responsibility for the program, monitors the results of the district calibrations, trains new operators, determines test procedures and specifications, and maintains the equipment.

In addition to the Mays meters maintained in each district, the central office has two trailers along with all testing equipment. One trailer is maintained in a calibrated condition for use by any district in the event of a major equipment problem. The other trailer is used as a calibrated standard trailer and for research purposes.

The total equipment package used in the testing program is as follows:

1. The Mays ride meter, which determines road roughness by measuring vertical movement between the axle and chassis of the test trailer;
2. The roughness trailer, which was designed for use in a roughness-testing program, weighs 800 lb/wheel, and measures 120 in. from axle to hitch;
3. The tow vehicle, which can be any vehicle capable of towing the roughness trailer;
4. The distance-measuring instrument, which electronically measures the distance tested to the nearest 0.001 mile;
5. The speed meter, an electronic unit built by the Georgia DOT to monitor testing speed to within ±0.2 mph; and
6. The digital roughness meter, an electronic display unit designed and built by the Georgia DOT that eliminates the Mays meter chart paper and provides a roughness and testing length readout with one-button operation (results of as many as 63 tests can be stored before the data have to be recorded).

CALIBRATION

The calibration of response-type roughness meters is a weak point of any roughness-testing program unless a true profile of the roadway can be obtained that then can be related to the roughness meter output. Equipment for obtaining such a profile is expensive and is not readily available to many agencies. The other alternative is to use test sections that have been established on in-service roads. This is the system used by the Georgia DOT.

Questions are always raised about the effect of the short-term and long-term increase in roughness of these calibration sections. One way to reduce the effect of these changes is to establish a number of sections on various roadways so that cross checks can be made. Central test sections (CTSs) have been established for calibration reference purposes. These sections are monitored periodically with the central office trailer and serve as an overall calibration standard.

After initial calibration on the CTS, each district established its own field pavement test sections. These sections are tested every 2 weeks to maintain accuracy. The central office calibration control trailer visits each district periodically to check the field test sections and randomly check current projects tested by the district.

Two field test sections are required for each district. Each section consists of a 1-mile length of roadway tested in each direction. One section has a roughness reading in the smooth range and the other section a reading in the medium-roughness range. These sections were carefully chosen to avoid features such as bridges, busy intersections, heavy traffic, and sharp curves.

Each section is initially tested 10 times to establish control limits. A mean roughness value and a range are calculated along with the control limits. Bimonthly calibration checks are plotted on the control charts to determine long-range trends and the calibration history of each road meter. An example of the use of such a control chart is shown in Figure 1. The use of different trailers for construction control dictated that all readings obtained by all trailers on the same section must be comparable. Conversion charts to correct actual readings to adjusted readings to account for calibration differences were deemed inappropriate for use on construction projects. In addition, frequent calibration makes it impractical to determine new calibration graphs often.

To eliminate calibration graphs or multiplying factors, the Georgia DOT is using a mechanical calibration arm to make adjustments. The mechanical adjustment device shown in Figure 2 basically changes the length of the lever arms between the chassis and the axle cables, thereby increasing or decreasing the input to the Mays transducer. This procedure permits fine tuning of the response system and allows each trailer to record identical responses to the road profile. The lever arm also allows for adjustments when a component of the trailer, such as shocks, must be replaced.

Another method of calibration that has been proposed in recent years is the artificial reference surface (ARS) (1). Correlations were made in 1980 by using the ARS and the roughness meters in use in Georgia. Initially, all trailers were adjusted to read the theoretical value of 16.2 in. when driven over the test surfaces (see Table 1). The trailers were then taken to two test sites and roughness readings were obtained with each trailer. The raw data were then corrected by using the appropriate correction equation as prescribed in the ARS procedure. The results of these tests and the corrections given in Table 2 indicate a wide range in test results in both the uncorrected and the corrected data, especially on the smooth section. The process was repeated for two different test sections with the same results.

The next step consisted of using the calibration adjustment arm on each trailer to obtain readings on a smooth road that were as close as possible to a target value. Tests were then made on a road with higher roughness to ensure that the trailers responded to the road profiles in the same way. The results of these tests, given in Table 3, indicate satisfactory agreement between trailers on the smooth and rougher test sections. Based on these test results it was apparent that the ARS method was not sensitive enough for test results obtained on smooth roads and therefore could not be used for calibration purposes by the Georgia DOT.

OPERATING PROCEDURES

The Georgia DOT operating procedures are detailed in a manual that is provided to each operator (2). All tests are made at 50 mph on construction projects with a maximum allowable speed variation of ±1 mph. Tested sections are normally 1 mile long. A minimum of two tests is required for acceptance testing, and the results must be within 10 percent or a third test is required. If none of the test results is within the 10 percent variation limit, the meter is taken back to the calibration section to determine the cause of the problems. Tests are not run when the air temperature is below 32°F; otherwise, no temperature corrections are made to the test results. Roughness caused by bridges and railway crossings is not included in the roadway test results. A Mays meter graph is generally provided only on preconstruction roughness tests, for failing sections during acceptance testing, or at the request of the engineer.

Figure 1. Example control chart for average roughness readings on smooth test section.

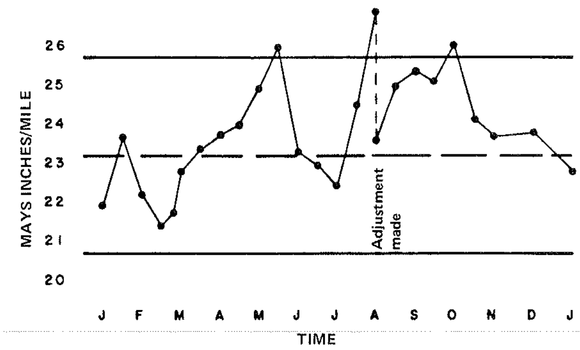
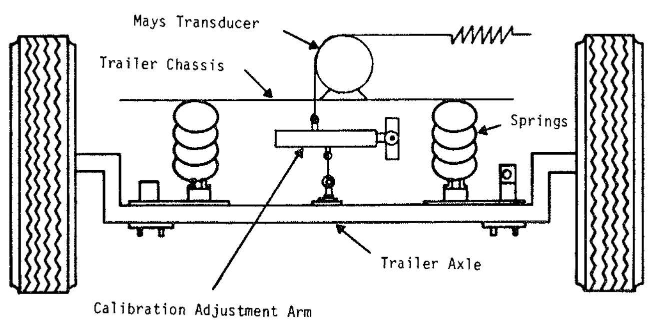


Figure 2. Calibration adjustment arm hookup.



SURFACE TOLERANCE SPECIFICATIONS

For several years Georgia DOT specifications have contained surface tolerance acceptance criteria based on use of the road meter. These roughness specifications have evolved over a period of years. The major steps are

1. Use of the rolling straightedge,
2. PCA meter run for information only,
3. Acceptance based on the PCA meter and straightedge testing of failed sections for penalty assessments, and
4. Use of response-type road meters for acceptance and rejection of projects.

The initial values in the specifications were determined from the information-only results obtained with the PCA meter. Realistic values were set that could be obtained with good construction practices. The Georgia DOT and contractors were familiar with the road meter and the kind of test results that were being obtained at the time the PCA meter was added to the specifications. Throughout the years the roughness limits were lowered as construction equipment and procedures were improved.

In 1980 correlations were obtained between the Mays meter and the PCA meter for the purpose of establishing Mays meter specifications at the same level as those established with the PCA meter.

The system currently in use in Georgia has different specification requirements for concrete pavements, asphalt pavements, and bridge decks. The surface tolerance requirements for asphalt concrete pavement are given in Table 4. The requirements for portland cement concrete pavement are as follows:

Table 1. Results of ARS tests.

		Mays Meter Reading[a] (in./mile)				
Trailer	Date	Both Wheels	Left Wheel Only	Right Wheel Only	Average	Calibration Equation
453	5/30/80	16.2	8.6	7.4	8.0	Y = 0.987X + 2.2
464	6/10/80	16.3	7.6	7.9	7.8	Y = 0.953X + 7.1
465	6/9/80	16.3	8.2	8.1	8.2	Y = 1.000X − 1.1
471	6/6/80	16.2	8.2	8.2	8.2	Y = 1.012X − 2.1
472	6/4/80	16.2	8.8	7.9	8.4	Y = 1.038X − 6.6
473	6/5/80	16.0	8.5	8.5	8.5	Y = 1.080X − 11.6
474	6/5/80	16.5	9.0	8.1	8.6	Y = 1.025X − 7.7
475	6/6/80	16.2	8.6	8.0	8.3	Y = 1.025X − 4.4
476	6/5/80	15.9	7.4	8.2	7.8	Y = 1.000X + 3.2
8967	5/30/80	16.9	9.2	9.1	9.2	Y = 1.052X − 16.9

Note: In tests 453 through 476 the Mays meter was mounted in a trailer; in test 8967 a Torino wagon was used. All trailers were set as close as possible to the theoretical ARS of 16.2 by using the lever arm adjustment. The Torino wagon could not be adjusted.

[a]Reading on ARS x 10.7.

Table 2. Measured roughness versus corrected roughness obtained by using the ARS method.

	Roughness (in./mile)							
	Ga.-7 (Milepost 0-1)				Ga.-362 (Milepost 4.5-5.5)			
	Northbound Lane		Southbound Lane		Eastbound Lane		Westbound Lane	
Trailer	Raw	ARS	Raw	ARS	Raw	ARS	Raw	ARS
453	27.1	28.9	33.0	34.8	56.0	57.5	64.0	65.4
464	20.3	26.4	19.5	25.7	56.3	60.8	54.1	58.7
465	19.8	18.7	22.4	21.3	56.8	55.7	60.0	58.9
471	21.2	19.4	24.3	22.5	56.9	55.5	55.4	54.0
472	22.4	16.7	27.2	21.6	57.5	53.1	56.5	52.0
473	24.1	14.4	27.2	17.8	56.3	49.2	57.4	50.4
474	29.2	22.2	34.8	28.0	61.1	54.9	59.8	53.6
475	37.3	33.8	39.2	35.8	62.1	59.3	62.7	59.9
476	24.2	27.4	28.0	31.2	60.3	63.5	58.4	61.6
Avg	25.1	23.1	28.4	26.5	58.1	56.6	58.7	57.2
Range	17.5	19.4	19.7	18.0	6.1	14.3	9.9	15.0
8967[a]	28.1	12.7	31.7	16.4	69.5	56.2	62.8	49.2

Note: Runs were made immediately after trailers were set on ARS.

[a]Torino wagon.

Location	Measuring Instrument	Roughness (in./mile)
Main line	Mays meter	65
Ramps	Profilograph	14

For ground concrete pavement the specifications require a value of 50 in./mile with the Mays meter and, if the pavement does not pass, a maximum of 7 in./mile with the profilograph. Finally, the specifications for bridge decks are as follows:

Direction	Measuring Instrument	Roughness
Longitudinal	Profilograph	15 in./mile
Transverse	Straightedge	0.2 in./10 ft

The requirements also vary within each pavement type.

These values are presented for information purposes only and would not necessarily be valid for Mays meters installed in vehicles or trailers that have different weights and wheelbases. Asphaltic concrete pavements have different requirements for new construction, open-graded friction courses, and non-Interstate resurfacing. The requirements also contain a target value that is the specification value and roughness levels at which correction of the surface will be required. For portland cement concrete pavements there are different requirements for new construction and ground concrete surfaces. The profilograph is used to determine smoothness on bridge decks and on ground concrete pavement surfaces that fail to meet the Mays meter requirements. The profilograph is used as a secondary acceptance tool on ground concrete surfaces because the grinding equipment can only remove small surface variations over short distances. Grinding of concrete pavement is not done to remove roughness caused by swells, dips, or severe settlement of the pavement, all of which affect road-meter results.

Table 3. Retest of trailers after setting on GA-7.

		Avg Reading[a] (in./mile)			
		Ga.-7		Ga.-3	
Trailer	Date	Northbound	Southbound	Northbound	Southbound
453	6/24/80	22.8	22.4	66.0	59.7
464	6/25/80	22.0	20.7	67.7	64.4
465	6/20/80	23.7	21.0	66.1	61.5
471	6/23/80	20.5	21.7	64.9	59.5
472	6/26/80	23.6	22.7	58.2	53.4
473	6/23/80	22.7	21.0	63.4	59.5
474	6/23/80	24.0	19.8	64.6	60.1
475	6/26/80	22.9	19.6	66.3	60.4
476	6/26/80	21.9	22.6	56.8	55.2
Avg		22.7	21.3	63.8	59.3

Note: All trailers set on Ga.-7 (smooth) and check made to see whether all read the same on Ga.-3 (rougher). Setting on adjusted average of all trailers: 23 northbound and 21 southbound on Ga.-7.

[a]Average of five runs after adjustment.

Table 4. Surface tolerance specifications for asphalt concrete pavements.

	Roughness (in./mile)			
	Open-Graded Friction Courses		Dense-Graded Mixes	
Type of Project	Target Value	Correction Value	Target Value	Correction Value
New construction and Interstate resurfacing	25	30	35	35
Other	25	35	35	45

Note: Applicable to main line and ramps more than 0.5 mile long.

USE OF ROUGHNESS DATA

Since 1972 the Georgia DOT has used a response-type road meter in acceptance of road construction projects for smoothness. The emphasis by the Georgia

DOT on obtaining smooth-riding roads has had a profound effect on the ridability of roads in Georgia. The trends since 1972 are clearly indicated in Figure 3, which shows the statewide roughness averages for the period in which the PCA meter was being used. The preconstruction roughness level has decreased substantially since 1972, and the smoothness levels of new construction and overlays have also improved steadily over the years.

The smoothness requirements forced contractors and field personnel to pay attention to smoothness in paving operations. Better scheduling of trucks, for instance, leads to fewer starts and stops and fewer joints, which cause ride discomfort. The emphasis on obtaining smooth-riding roads is further aided by giving the project engineer roughness results during construction on the leveling, intermediate, and final surface layers. These early results allow for correction during the construction process and result in fewer surprises when the final surface is tested for ridability acceptance.

The recently adopted Mays meter system gives a graphical representation of the roughness input to the meter and can be used by the engineer to determine where leveling is required. In addition, when corrections are to be made to the final surface course, it allows the engineer to pinpoint the locations that need corrective work. An in-depth analysis can be conducted by the engineer or the contractor from the Mays meter graph by plotting the roughness level for each 0.05 mile or any other convenient length versus distance as shown in Figure 4. The graph shows that the roughest section is located between mileposts 6.6 and 6.9. The roughness represented in Figure 4 could be caused by poor construction joints or other problems. This should be verified in the field. Corrective actions could include resurfacing and other methods.

The smoothness levels obtained on construction projects are compiled on a quarterly basis for all completed projects. This report contains rankings for overall smoothness by highway districts and by contractors. The report is distributed throughout the Georgia DOT and to each contractor listed in the report. This fosters a competitive spirit among the highway districts and among individual contractors. The report contains data that compare the roughness values obtained statewide with the specified values, and the roughness obtained for each of the various asphaltic concrete surface mixes is compared.

CONCLUSIONS AND RECOMMENDATIONS

Based on the Georgia DOT experience, the following conclusions have been drawn.

1. The response-type road meter is a rapid, inexpensive instrument that can be used to monitor the ridability of road construction projects.
2. Calibration is a problem and frequent calibration checks are necessary when the roughness meter is used for acceptance or rejection of construction projects.
3. Shock absorbers are the most common reason for roughness meters being out of calibration.
4. Specifications for surface tolerance must be realistic, and the limiting values should be established based on results obtained on projects that have acceptable ride quality.
5. The inclusion of the PCA meter and the Mays meter in the specifications has improved the overall ride quality of Georgia roads.

It is recommended that

1. Research continue on improving calibration

Figure 3. Historical trends of roughness levels in Georgia.

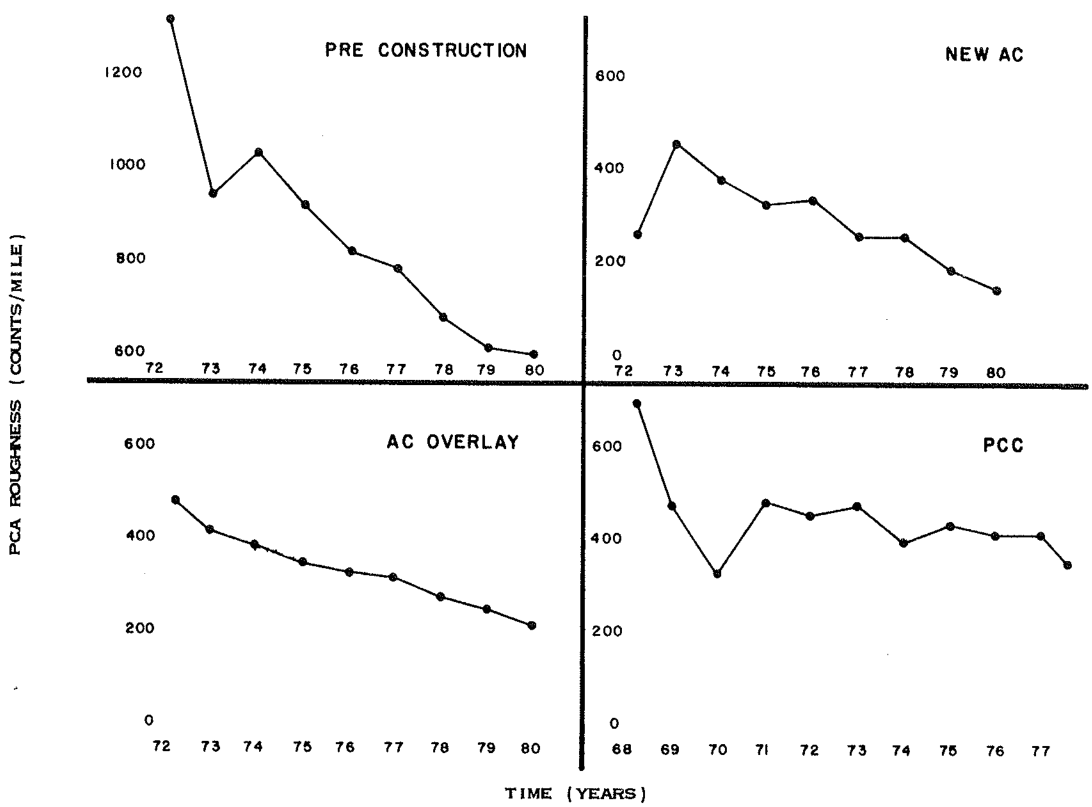
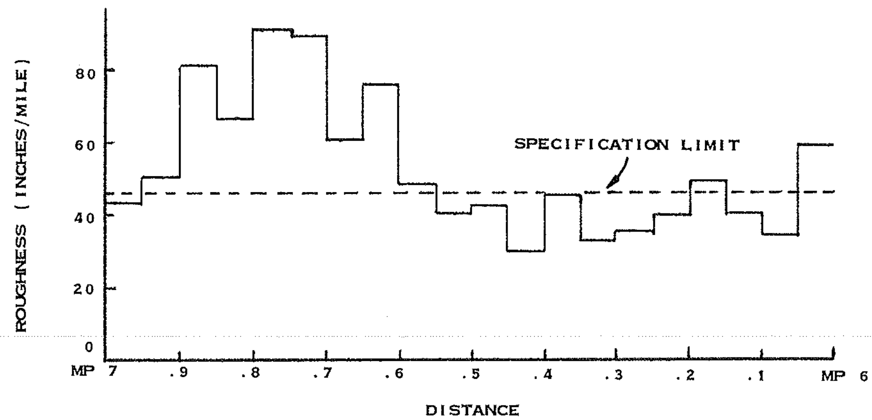


Figure 4. Distribution of roughness plotted from Mays Meter graph.



devices, especially on developing low-cost devices for measuring pavement profiles;

2. High-quality shock absorbers designed for roughness testing be made available; and

3. Any agency that wants to adopt ridability values established by other agencies do so only after correlations have been obtained between the roughness meters of the two agencies.

REFERENCES

1. T.D. Gillespie, M.W. Sayers, and L. Segal. Calibration of Response-Type Road Roughness Measuring Systems. NCHRP, Rept. 228, Dec. 1980.
2. Georgia Mays Meter Control Procedures and Operators Guide. Georgia Department of Transportation, Atlanta, Oct. 1980.

Penn State Automatic System for Collecting and Processing Road Meter Records

M.J. FLEMING, J.C. WAMBOLD, AND G.F. HAYHOE

A microcomputer-based data acquisition and processing system developed as a replacement for the Mays ride meter is described. The system retains the same basic operational characteristics as the Mays meter but offers improvements in resolution, cost-effectiveness, and ease of use and requires a minimum of operator training. System operation is interactive, and the operator is prompted by an alphanumeric display and backlighting of the data input keyboard. Highway event data and road roughness measurements are stored on magnetic digital cassette tape for automatic transfer to a road inventory or pavement management system data base.

The vehicle-mounted Mays ride meter (MRM) is widely used by highway departments to make records of road roughness. These records are used to inspect new construction and to determine the maintenance needs of existing roads. A modification of the commercial MRM system was designed at the Pennsylvania Transportation Institute by Bhargava (1). The system replaced the graphical output of the commercial MRM system with printed numerical output from an onboard computer. The system uses the photocell-based transducer used in the commercial MRM to measure roughness input.

The development of a system that uses an incremental digital encoder as the transducer is described in this paper. The system was developed in cooperation with the Pennsylvania Department of Transportation (PennDOT) to perform onboard processing of the encoder output and to store the resulting measurements of road roughness on a digital cassette tape recorder.

COMMERCIAL MAYS RIDE METER

The commercial MRM operates in a vehicle traveling at highway speeds and is powered by the vehicle's 12-V electrical system. There are two main components of the system: the transmitter, which measures the motion of the rear axle in relation to the vehicle body, and the recorder, which records data from an odometer, an event button, and the transmitter.

The transmitter is attached to the body of the vehicle above the differential. Digital signals sent to the recorder by the transmitter indicate the movement of the rear axle in relation to the vehicle body with a resolution of 0.1 in. (0.25 cm). The