FINAL REPORT

EVALUATION OF A K. J. LAW MODEL 8300 ULTRASONIC ROUGHNESS TESTING DEVICE

K. H. McGhee
Research Consultant

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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16. Abstract

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It was found that, with certain limitations, the Surveyor (sn 1372) is capable of correlation with other roughness testing equipment and of providing test results meeting the requirements of HPMS Class II equipment. Among the major limitations are the following: (1) on coarse-textured surfaces, the device is highly sensitive to variations in testing speed, and (2) the device is highly sensitive to changes in ambient temperature. The author concludes that these limitations are too severe for the device to be used in any except very uncritical roughness testing.

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ABSTRACT

A study of the K.J. Law Model 8300 Roughness Surveyor was begun in 1985 to determine the feasibility of replacing Mays Meter roughness testing equipment with an easier to use and more repeatable alternative. The original schedule called for completion of the study in late 1986. However, the study was badly delayed because of equipment failures, long delays by the manufacturer when the equipment was returned for trouble shooting, and altered priorities placed on the research staff. Because of these altered priorities, the study was tabled for several years so that final testing was not completed until mid-1991.

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INTRODUCTION

The increasing interest over the past few years in pavement management systems has led to a parallel increase in interest in the development of refinements in road roughness measuring systems. Although roughness measuring equipment historically has been used primarily for research purposes in many transportation agencies, it is rapidly becoming an operations tool for obtaining information used in pavement management. Further, increased awareness of pavement ride quality is providing impetus for the development of roughness or smoothness specifications. In addition, the Federal Highway Administration now mandates periodic roughness tests on the Highway Performance Monitoring System (HPMS) sites in each state.[1] With some 3000 such sites in Virginia, this requirement alone makes roughness testing a priority activity.

In Virginia, the size of the highway system and the need for large quantities of ride quality data in pavement management make the conventional response type road roughness measurement (RTRRM) system (currently the Mays meter) totally inadequate. Although RTRRMs measure ride quality at traffic speeds, analysis of the data they provide is often so laborious and time consuming that much more time is expended on analysis than on roughness testing. Further, since the output of an RTRRM is strongly influenced by the characteristics of the suspension system of the carrier vehicle (usually a passenger car), the data from different RTRRM's cannot be easily compared, and their outputs are not constant over time because the characteristics of the suspension systems change with deterioration of the components. These differences in characteristics among vehicles and over time also make the RTRRM a very difficult tool to use in the specification and acceptance of construction ride quality. Neither the specifying agency nor the contractor is satisfied with a measuring tool with such variable output and poor repeatability. As pointed out in a recent national research study, RTRRM systems are satisfactory for road network surveys, but the inherent random error limits their usefulness in the evaluation of individual roadway sections, especially on new construction.[2] With a view to solving the problems outlined above, a new generation of roughness measuring equipment has been developed. The major development (which provides what appears to be much improved reliability in roughness measurements) is that the new systems promise to be independent of the carrier vehicle and largely unaffected by variations in testing speed and by environmental changes. These improvements relate primarily to the use of accelerometers, which sense and cancel carrier vehicle vertical movement and thus measure only deviations of the roadway surface from a horizontal plane.

The most well-known device incorporating the above principle is the profilometer developed by the General Motors Corporation and utilized by some agencies for nearly 20 years.[2, 3] While the profilometer output yields a true pavement profile, its cost (over $300,000) makes it too expensive for most highway agencies to own in sufficient numbers to use for pavement management inventories or for construction quality control and acceptance. For this reason, several manufacturers have adapted many of the characteristics of the profilometer to a passenger-car-mounted roughness measuring system selling at a fraction of the price of a profilometer.

The device selected for evaluation in the present study is the Model 8300 Roughness Surveyor manufactured by the K. J. Law Corporation. The surveyor was selected on the basis of the trade literature, its availability, and price (approximately $35,000). The Model 8300 Surveyor is a passenger-car-mounted pavement roughness testing device. The system senses pavement elevation through an ultrasonic transmitter and sensing unit. The model evaluated in the present study was configured with only one sensor to collect data in one wheelpath. The frequency of the transducer is such (150 Hz) that the elevation is measured approximately every 6 inches at 55mph. The ultrasonic unit is coupled to an onboard microcomputer, which accomplishes data analysis and output. Output is to a liquid crystal display and to a Model RX-80 Epson printer. Data are also captured on a cassette for later input to personal or mainframe computers. Distance measurement is through an electromechanical linkage to one wheel of the vehicle with input directly to the onboard computer (see Figure 1).

Surveyor output may be varied somewhat at the request of the user. As furnished to Virginia, output is in terms of root-mean-square vertical acceleration (RMSVA), a measure of the acceleration imparted to the vehicle by road deviations from the horizontal and predicted Mays Meter roughness based on idealized (known as Golden Car) inputs as defined in a report by the National Cooperative Highway Research Program.[2] Because the relationship between the two output parameters is essentially mathematical, the focus in this study was on the predicted Mays Meter roughness with which Virginia managers are familiar. Unlike the profilometer, the Surveyor, because of its limited computer capacity, cannot provide a direct output of the road profile.

PURPOSE AND SCOPE

The purpose of the present study was to evaluate the effectiveness of the Model 8300 Roughness Surveyor as

1. an inventory tool
2. a construction quality control and acceptance tool
3. a research tool.

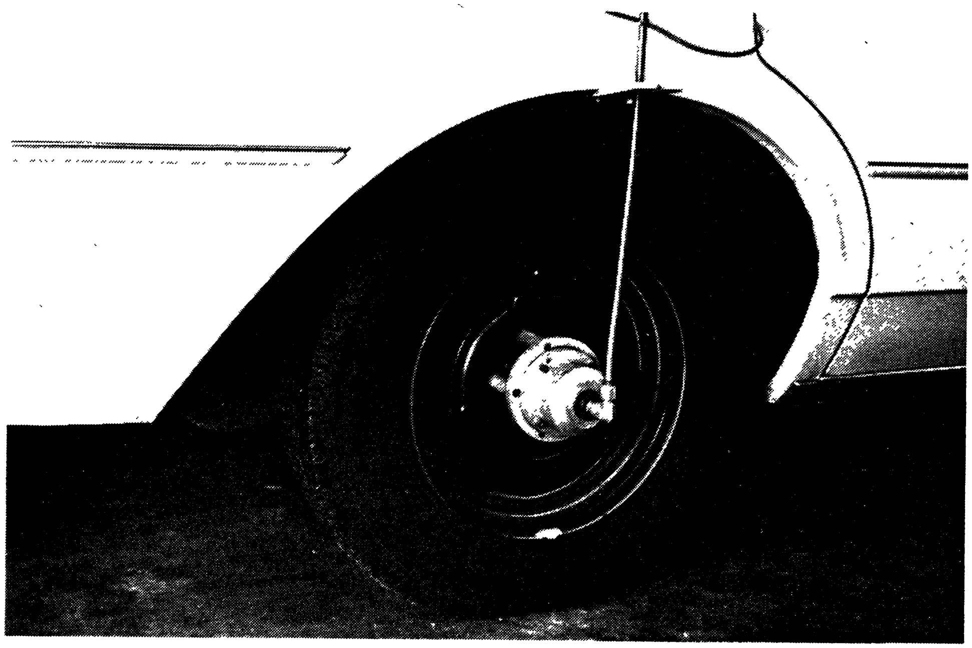

Figure 1. Distance-measuring instrumentation.

Each of the above uses places somewhat different requirements on the equipment. For example, in inventorying, the speed of data capture and analysis is more important than high resolution and high repeatability. On the other hand, for construction control and acceptance purposes, the ability to provide highly reproducible results at a moderate rate of testing is most important, because the data may need to be legally defensible. If the equipment is capable of both speedy data handling and good reproducibility, it will be satisfactory for research purposes.

METHODOLOGY

Virginia's Experience With the Model 8300

For more than 5 years, we attempted to secure usable data with the Model 8300 Roughness Surveyor. The original Surveyor was delivered in July 1985 and installed on a 1979 Chevrolet Impala passenger automobile. Installation was on the rear bumper to measure the right wheelpath. This version of the Surveyor, was referred to as the "canister" type because of the configuration of the transducer/accelerometer. The unit provided to Virginia was assigned serial number 1086.

Early evaluation plans called for testing to begin by early 1986 and to be completed by September of that year. However, even early efforts to secure meaningful results were unsuccessful because of "static" in the electronics providing output. As a result, the device was returned to the manufacturer in April 1986. Study records do not indicate when the Surveyor was returned to the state, but do show that usable data were collected for a short time in the fall of 1986. Soon, however, erratic results caused another return to the manufacturer in January 1987. At that time, sufficient data had been collected to provide the following tentative conclusions:

1. Correlations between the Surveyor and a Mays Ridemeter were acceptable. The correlation coefficients were 0.92 to 0.99.
2. The surveyor had better day-to-day repeatability than the Mays.
3. The surveyor was highly sensitive to testing speed.
4. The surveyor was useless on open-graded mixtures and chip-sealed pavements where coarse surface textures prevail.

When the device was returned the second time, the author informed the manufacturer of the above results and admonished the company to upgrade the next generation Surveyor to state-of-the-art technology including an IBM compatible computer and a CRT display.

The device was redesigned (not as recommended by the author) and returned in late 1987, and a new evaluation began in February 1988. This version of the Surveyor utilized a much more compact transducer (see Figure 2) and was assigned serial number 1372. Documentation from the manufacturer with this unit indicated that computer internal components also had been upgraded and replaced. The redesigned device still performed erratically and was returned to the manufacturer a third time on August 22,1988. This time, the Surveyor was returned to the author in October 1988 at a time the research staff was committed to other activities and could not pursue the evaluation.

Another effort to complete the study was undertaken in late 1989 at which time the device was still found to yield erratic results. The Surveyor was returned to the manufacturer a last time in early 1990. In May 1990, a manufacturer's representative arrived with the device and assisted in installing the machine, this time in a 1989 Chevrolet Impala. This version was installed on the front bumper to measure the left wheelpath. At that time, the manufacturer admitted that the problem with the device had been in a faulty keyboard (it is clear to the author that the keyboard may have been a major culprit for the full 5 years the study had been underway). Further testing of the device yielded reasonably good results until the fall of 1990 when erratic results again occurred. At that time, a representative of the manufacturer admitted that the surveyor was unstable in cold weather and that tests should not be conducted when temperatures were below about 60° F.[4]

The temperature limitation was taken by the author as a final indication that the model 8300 Surveyor was a seriously limited piece of equipment and that little further testing effort was warranted. The author has since received a sales

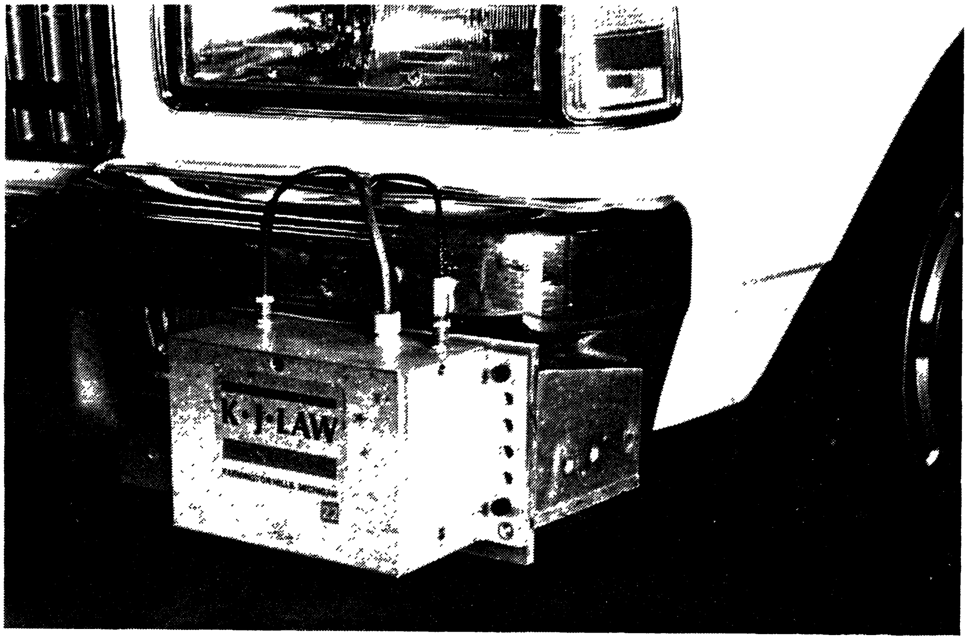

Figure 2. Redesigned Surveyor (SN 1372).

brochure from the manufacturer stipulating a lower testing temperature limit of 40° F for a Model 8300A Surveyor.

Test Sites, Vehicles, and Speed

It was originally envisioned that much of the data necessary to the study would be gathered in a testing program on eight sites used for many years in maintaining and checking the calibration of the Mays Ridemeters. The pavements at these sites, all of which were constructed in 1970 of continuously reinforced concrete, have exhibited very stable ride quality over time, cover a range in roughness of approximately 60 to 120 in/mi as determined by the Research Council's Mays Meter mounted in a 1979 Chevrolet Impala. A large amount of historical data for these pavements is in the Research Council's files. However, this study was of such duration that perceptible changes began to take place on the calibration sites (patching, etc. contributed to increased roughness) so that several other sites were chosen on the basis of desirable roughness level or pavement surface type (texture) and tested with both the Mays Meter and the Surveyor. These sites will be described in the ensuing discussion.

At the inception of the study, it was expected that all studies of the Surveyor would be conducted with it mounted in the same 1979 Chevrolet Impala used for Mays Ridemeter research and routine testing. However, as noted in the earlier discussion of experience with the 8300, the study outlasted the 1979 automobile, which was replaced with a 1989 model of the same type and size. In the ensuing discussion, the distinction between automobiles used for the various tests will be made, although there appear to be no significant effects of that variable. Although not often used to do so, both vehicles were capable of running Mays and Surveyor tests simultaneously. Even when not in operation, both devices were installed in the vehicle at all times so that no differences in vehicle weight distribution occurred as a result of removing and replacing equipment.

Unless otherwise noted in the following discussion, all testing was at normal highway speeds, i.e., approximately 55 mph. The vehicle cruise control was used to maintain a speed as close to the desired speed as possible.

Testing Program

The testing program outlined below was considered necessary to the proper evaluation of the Surveyor within the scope of the study. Details of the various elements will be discussed further under the results section.

1. Repeatibility Studies. Studies of both same-day and day-to-day repeatibility were necessary to assess the capability of the Surveyor to serve as a suitable tool for the testing of HPMS sites and as a construction ride quality acceptance tool. These tests were evaluated in the context of bias requirements in the HPMS roughness testing methodology.[1] These requirements are summarized in the Appendix.

2. Correlation between the Mays Meter and the Surveyor. The large data bank of Mays roughness information on hand dictated that, to be fully useful, the surveyor must correlate well with the Mays Meter over a wide range of roughness values.

3. Sensitivity to vehicle speed. The usefulness of a Mays Meter in urban testing or other areas of restricted operations is severely limited as a result of its strong dependence on the speed of the testing vehicle. The examination of this issue was necessary to determine whether or not the Surveyor had similar limitations.

4. Surface texture effects. Significant effects of the surface texture of pavements on Surveyor results have been detected by other researchers.[5] Results are reported to be affected by coarse textures that cause scatter of the ultrasonic waves as a result of which there is insufficient return to the transducer and the computer issues an error message. Although the manufacturer supposedly had corrected this deficiency, caution against such a possibility was exercised in the current study.

5. Sensitivity to testing temperature. Sound wave propagation is influenced by the temperature of the medium through which the sound travels, in this case, air. For this reason, the surveyor supposedly has a built-in

temperature-compensating device. However, the experience with the Surveyor suggested that ambient temperature at the time of testing still could significantly influence test results. The researchers, therefore, had to be alert to such effects and recorded air temperature at the time each test site was run.

RESULTS AND DISCUSSION

Although each of the series of tests outlined above was conducted (or at least attempted) at various times throughout the study, only those conducted in 1990 with the last version of the Surveyor (SN 1372) provided by the manufacturer are discussed in depth below. The author is not in a position to know details of technical differences between the earlier "canister" version and the much more compact version supplied later. Therefore, one could only speculate about similarities in performance of the two machines.

Repeatability Testing

The results of Model 8300 repeatability testing are summarized in Table 1. The averages and standard deviations of predicted Mays roughness values for 30 replicate tests on the sites listed and for the times listed were calculated. Then the standard equation to estimate the number of tests required was applied assuming a 95 percent confidence level would be acceptable with a 5 percent tolerance (i.e., the user of the instrument could be 95 percent confident that the real roughness was within 5 percent of the indicated value.) This equation is

$$N = (t \times v / E)^2$$

where N is the number of repeat tests required to achieve the desired confidence level, t is a probability factor (2 for 95 percent confidence level), v is the coefficient of variation, and E is the tolerance (5 percent in this case).

Three different pavements were analyzed as above (see Table 1). The first was a fine-textured pavement, which was measured on two different days; the se-

Table 1
SUMMARY OF REPEATABILITY TESTS
30 TESTS PER SITE

Location	Mix Texture	Date	Avg. Surv. (in/mile)	Std. Dev. (in/mile)	Coef. Var. (%)	95% Conf. No. Tests Req.
Rte. 29S	Fine	6/22/90	99.9	3.1	3.1	2
Rte. 29S	Fine	6/27/90	104.0	2.3	2.2	1
Rte. 732W	Med.	6/28/90	281.5	4.8	1.7	1
Rte. 37	Course	7/09/90	78.0	3.4	4.4	3

cond was medium textured; and the third was coarse textured. The designation of relative textures was based on judgments made by the research staff and were not objectively measured in any way. However, the properties of surface mixtures and the general textures produced were known in each case.

The number of tests required for a 95 percent confidence level ranged from 1 to 3 depending on the pavement tested and on the date tested. Although the standard deviation tends to increase with roughness value, the inherent variability as measured by the coefficient of variation (the percentage ratio of the standard deviation to the average) does not. In fact, the roughest pavement was determined to have the lowest coefficient of variation and, therefore, the lowest required number of replicate tests. For all three pavements, the Surveyor results fell within the FHPM requirements for a Class II (direct profile) roughness testing device if one assumes the predicted Mays roughness is approximately the International Roughness Index (IRI) and the coefficient of variation is the measure of bias, as seems to be the intent of the requirements. The FHPM requirement on Class II instruments is a bias of less than 5 percent at a measurement interval of no more than 2.0 ft (see the Appendix). Within the limitations of the tests set forth in this section, the Surveyor appears to have acceptable repeatability. No significant effects of pavement texture were evident in these tests. However, as will be seen later, pavement texture may have a strong interaction with testing speed, which seriously affects test results.

Correlations With Other Roughness Testing Equipment

Within a period of several weeks in mid-1990, a series of 31 Mays Meter/Surveyor correlation tests were conducted. In keeping with a Virginia standard procedure used for Mays Meter calibration checks, five replicate tests were run on each site for each instrument. Each site is at least 1 mile in length. These averages of the five replicates are plotted graphically in Figure 3. Note that the regression equation has a coefficient of determination (R^2) of 0.966, indicating a very strong relationship between the two machines. On the other hand, a standard error of 12.8 shows that one could be reasonably certain (95 percent) that the Surveyor would predict the Mays results only within about 25 in/mile (two standard errors). In other words, the Mays roughness predicted by the Surveyor should be within 25 in/mile of the measured Mays roughness 95 percent of the time. Although such an error is probably quite satisfactory for pavement management purposes, it would be totally inadequate for construction quality control purposes where contract pay items could be involved.

It is important to note that fundamental differences in the operating principles of the Surveyor and the Mays Meter may make correlations inadequate as criteria for some pavements. An example would be roughness of such a character that pitch and roll motions could be sensed by the response-type Mays Meter, whereas only surface deviations from the horizontal plane would be detected by the Surveyor. Efforts to better define such effects were not within the limited scope of the present study.

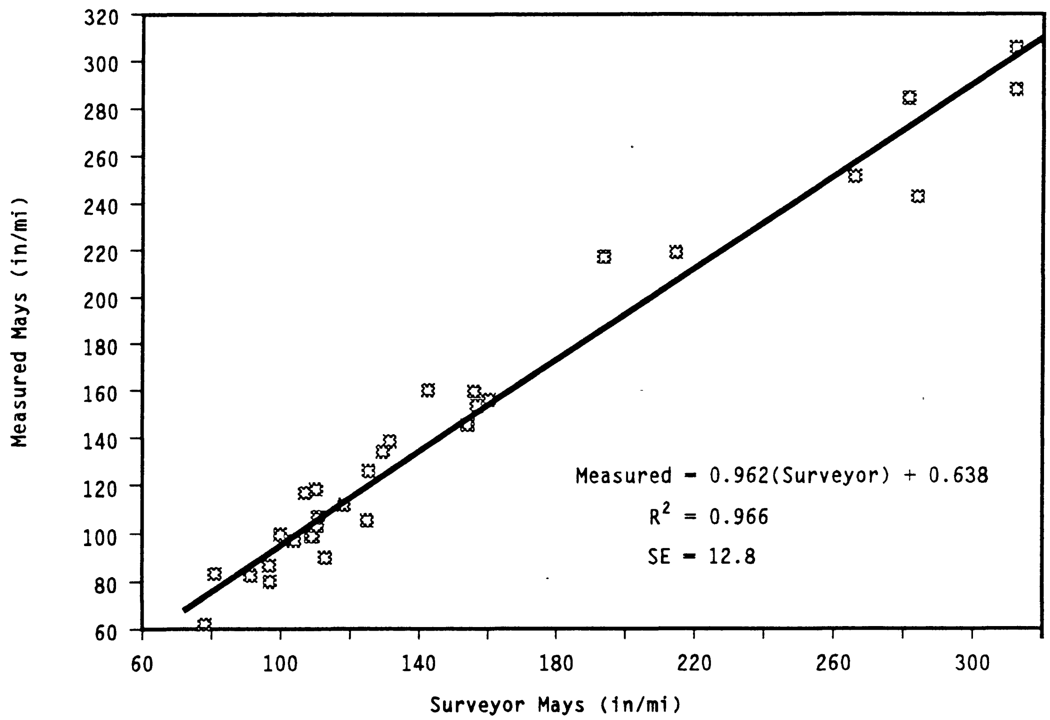

Figure 3. Mays Meter roughness v. Surveyor-predicted Mays roughness.

Sensitivity to Vehicle Speed

To examine the sensitivity of the surveyor to speed, tests were run in July 1990 on 1-mile-long segments of four different pavements. Testing speeds of 15, 35, and 55 mph were used (see Table 2). Each segment was tested 10 times with the surveyor. The pavement surfaces tested consisted of an open-graded friction course having a very coarse texture, a fine-textured slurry seal, a fine-textured hot-mix asphaltic concrete, and a chip seal (usually coarse textured). These data are plotted graphically in Figure 4, where the statistical findings discussed below are apparent.

Table 2
EFFECTS OF TESTING SPEEDS ON IRI

	Speed (MPH)		
Mix Type	15	35	55
Open Graded	118	143	190
Fine Slurry Seal	81	77	82
Fine HMAC*	100	100	100
Chip Seal	255	263	268

* HMAC = Hot mixed asphalt concrete

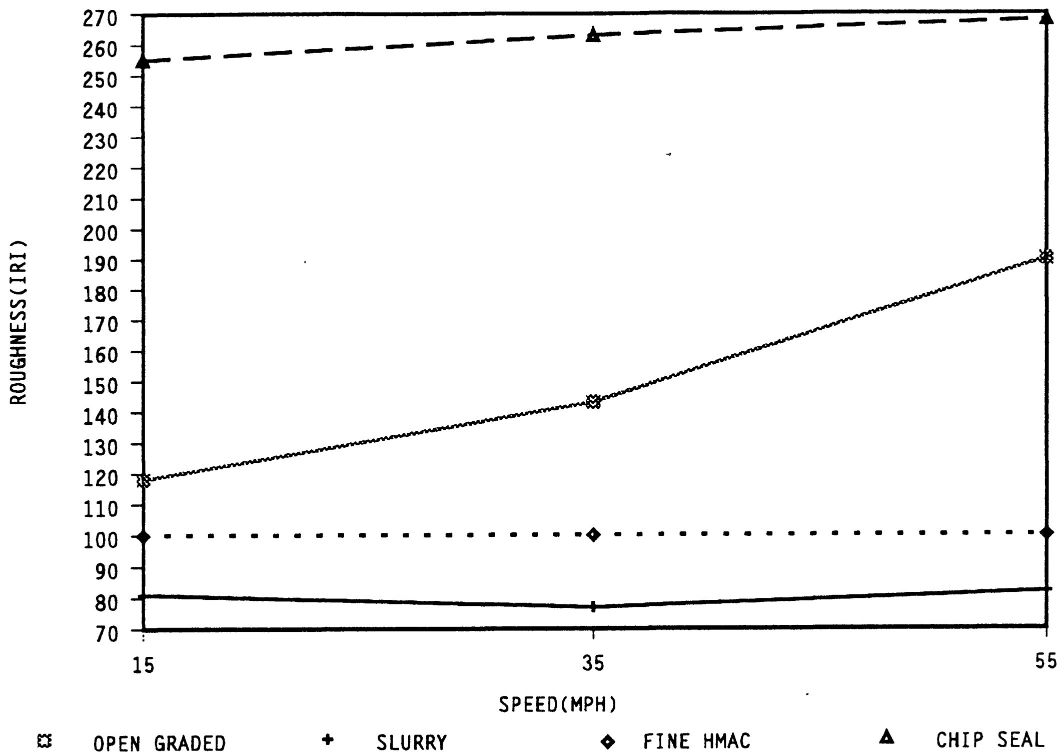

Figure 4. Effect of mix type on 8300.

For the open-graded surface, *t* tests show 99.9 percent probability that there are significant effects of vehicle speed on the predicted Mays roughness obtained using the Surveyor. It is further clear from the data that these effects of speed are large in magnitude as shown by the average values of 118, 143, and 190 in/mile for 15, 35, and 55 mph, respectively. Effects of speed, although not as readily apparent, also are statistically significant for the chip-sealed surface. Speed had no significant effect on roughness for the fine-textured slurry seal or the HMAC. One might argue that the ultrasonic signals are scattered by coarse textures, whereas most of the impulses are returned to the transducer on fine textures. Whatever the cause, on coarse-textured surfaces, the test results still are not consistent with those specified and expected, i.e., the Surveyor should be speed independent. As long as that feature exists, operators will never be quite sure when they should be concerned about texture effects and when such effects may be ignored.

These tests were conducted with the last version of the Surveyor (SN 1372) furnished to Virginia. Although progress was made in the later versions of the device, it appears that the Model 8300 Surveyor still is not an adequate roughness testing device for many of the purposes given earlier in the study.

The Effects of Ambient Temperature

Following the manufacturer's admission that the 8300 was still sensitive to testing temperatures, the researchers conducted a last series of tests in July 1991.

These tests were directed at determining the magnitude and nature of the influence of temperature with the hope that a mathematical correction could be developed. Tests were run on four pavement sections all with HMAC surfaces. It was reasoned that surface texture variations would not be significant among the four surfaces. Further, it was known from earlier experience that the HMAC shows little if any change in ride quality with changes in air or pavement temperature. Four replicate tests were run at each site. In each case, the air temperature (determined by a hand-held thermometer), the air temperature determined by the sensor built into the 8300, and the pavement surface temperature were recorded.

The results of these tests are given graphically in Figures 5,6, and 7. In each graph, there is a strong upward trend in roughness with increased temperature. However, in no case, are the lines straight or parallel—so there appears to be little hope that mathematical corrections would be appropriate. The researchers abandoned the temperature correction effort on the Model 8300.

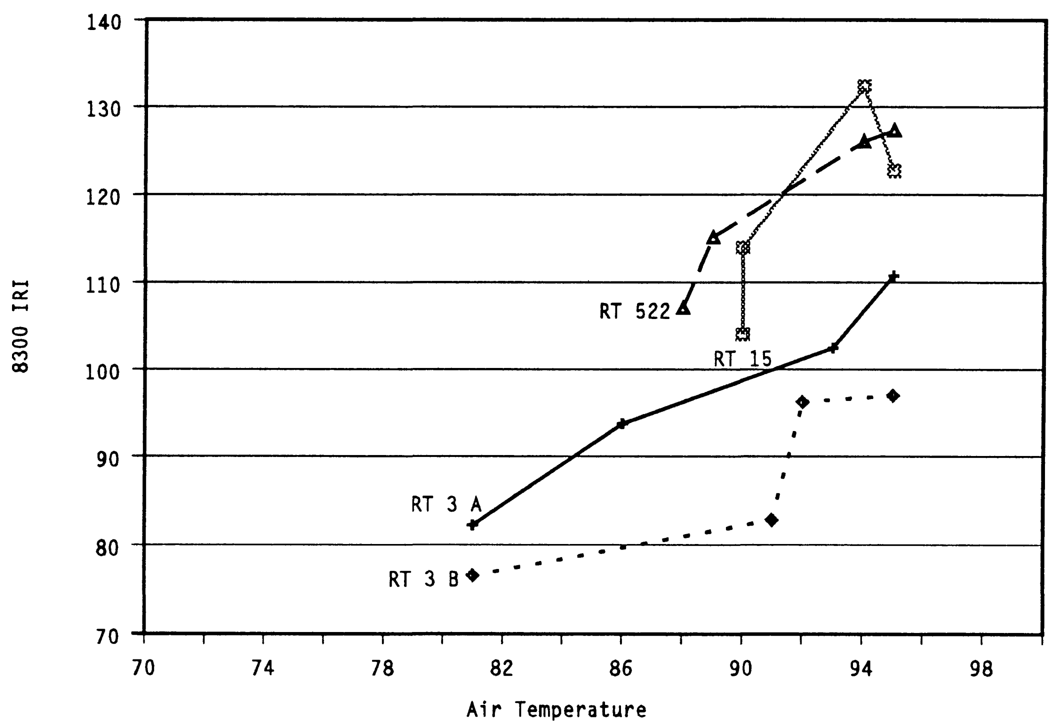

Figure 5. 8300 IRI v. temperature (7/18/91).

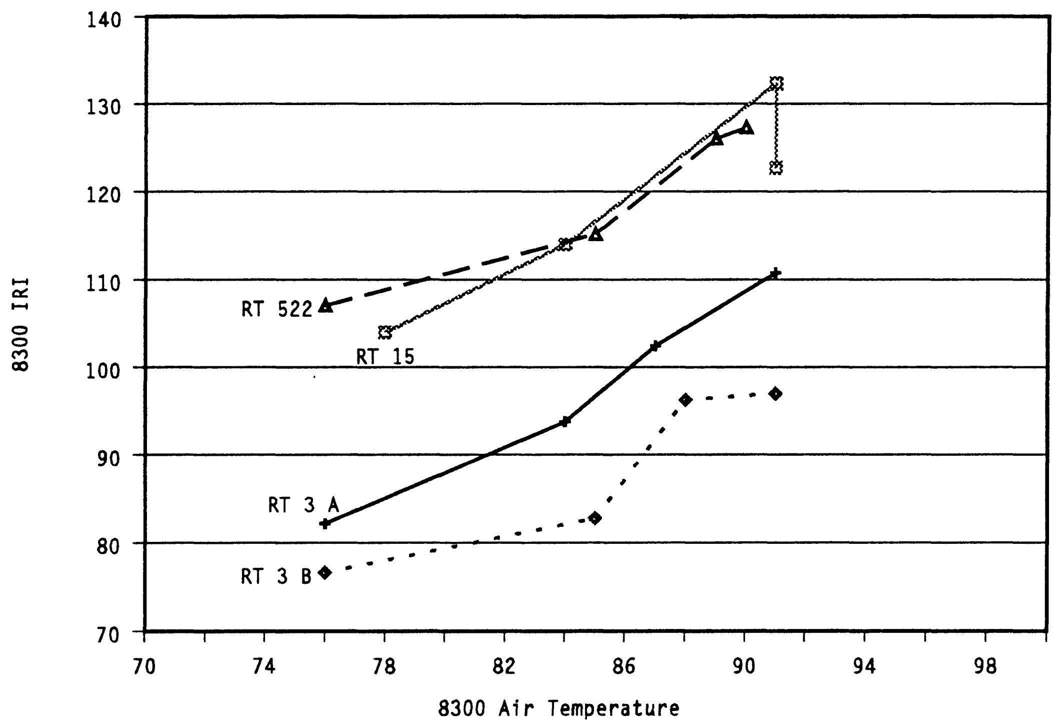

Figure 6. 8300 IRI v. temperature (7/18/91).

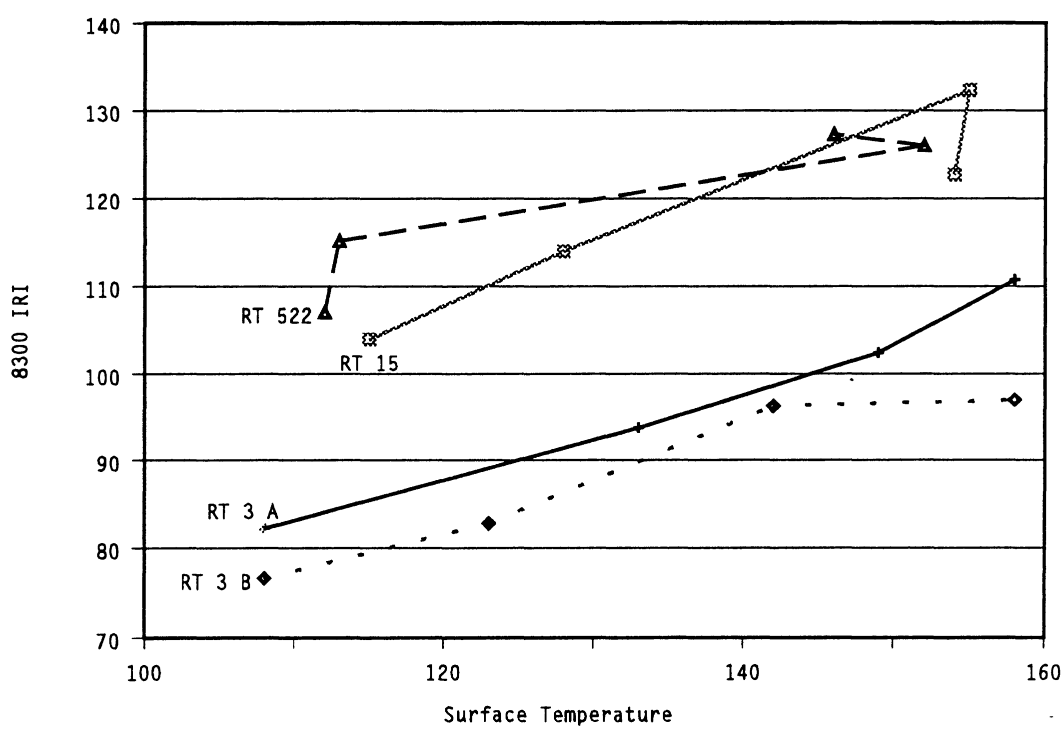

Figure 7. 8300 IRI v. temperature (7/18/91).

CONCLUSIONS

The studies reported above show :

1. The Model 8300 Roughness Surveyor is a useful roughness testing device with serious limitations.
2. A major limitation of the Surveyor on some pavement surfaces is the strong influence of testing speed on roughness test results.
3. Another limitation is in the significant and unpredictable influence of temperature on the test results.
4. With the above limitations, the Surveyor generally is sufficiently reproducible to meet the requirements for testing of HPMS sites.
5. When both the 8300 and the Mays Ridemeter are functioning properly, there is a good correlation between the two instruments. Yet, ride quality measurements on the same pavement at the same time by both instruments may differ significantly.

RECOMMENDATION

Because of the poor experience with the Model 8300 Roughness Surveyor, it would not be recommended as the "equipment of choice" for someone in search of a routine roughness testing device. The surveyor, with proper attention to detail, may be adequate for inventory roughness testing in a pavement management system. The device is totally inadequate as a construction quality control or acceptance tool or for research purposes.

ACKNOWLEDGMENTS

As a result of the long duration of the present study, a number of people played some role in the testing, the data analysis, and the report preparation. The author is especially appreciative of the efforts of R. W. Gunn, materials technician supervisor, L. E. Wood, Jr.,technical specialist, and Joyce Steed, research assistant, who were involved in the testing and data analysis as well as most of the frustrations of equipment failure. Thanks are also extended to J. L. Mills, laboratory mechanic, who had to substantially modify two passenger cars to accommodate the equipment.

The research was conducted under the general direction of Howard Newlon, Jr. and Dr. Gary R. Allen, directors of the Research Council. Funding was provided by the Federal Highway Administration through the HP&R program.

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Appendix

LIST OF EQUIPMENT TYPES AND MAXIMUM ERROR BY CLASS

I.	Manual Profiling Techniques Example: Road and Level	1.5 % bias; 0.3 m/km = 19 in/m	< or = 1.0 ft
II.	Direct Profiling Equipment Example: South Dakota Profilometer	5 % bias; 0.7 m/km = 44 in/m	< or = 2.0 ft
III.	RTRRM's* Example: Mays Ride Meter	10 % bias; 0.5–1.0 m/km 32–63 in/m	
IV.	Not suitable for use in collecting roughness data for HPMS.		

We advise any state considering purchase of new equipment or enhancing older equipment to require the marketing agent/manufacturer to demonstrate that the new equipment will perform at the precision of the stated class level prior to purchasing any new instrumentation to collect roughness data.