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2005 ACPA PROFILER REPEATABILITY TESTS

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16. Abstract

This report describes testing of profiler repeatability on four sections of textured concrete, including transverse tining, longitudinal tining, diamond grinding, and light turf drag. The profilers included only devices with a large height sensor footprint. The evaluation of repeatability was based on the level of cross correlation between repeat profile measurements after the application of the filters used in the IRI calculation.

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Acronyms

ACPA — American Concrete Pavement Association

ASTM — American Society for Testing and Materials

ATV — All Terrain Vehicle

DOT — Department of Transportation

ICC — International Cybernetics Corporation

IRI — International Roughness Index

SSI — Surface Systems Instruments

SUV — Sport Utility Vehicle

UMTRI — University of Michigan Transportation Research Institute

Summary

The ACPA rated the repeatability of five profilers on four concrete test sections with diverse smoothness and texture: (1) a very smooth diamond ground section, (2) a moderately rough transversely tined section, (3) a smooth longitudinally tined section, and (4) a smooth section with a drag texture. Each profiler measured 4-6 profiles on each section. Repeatability was quantified through objective comparison of profiles, using only those features that contribute to the IRI.

The Ames Engineering lightweight profiler with a RoLine height sensor demonstrated good or excellent repeatability on all four test sections. The Ames Engineering lightweight profiler with the TriODS laser system and the Ames Engineering high-speed profiler with the TriODS laser system demonstrated good repeatability on the longitudinally tined section and excellent repeatability on the transversely tined section and the drag texture. The Dynatest Mark IV high-speed profiler demonstrated excellent repeatability on the transversely tined section and good repeatability on the drag texture. Table 1 lists the profilers that qualified as having good and excellent repeatability on each section. The individual ratings appear in Table 5.

Note that the two Ames Engineering lightweight profilers were operated with an on-board apparatus that helped the driver maintain an accurate and consistent lateral position during the tests. The repeatability ratings cited above pertain only to the use of these devices with this apparatus.

These tests showed that repeatability of profile measurement on longitudinally tined pavement and diamond ground pavement depends heavily on the use of a large height sensor footprint and consistent lateral tracking of the profiler.

Table 1. Repeatability Classification.

Device	**Test Section**			
	Grinding	Trans. Tining	Long. Tining	Drag Texture
SurPro 2000				
Ames LW/TriODS		●	○	●
Ames LW/RoLine	○	●	●	●
Ames HS/TriODS		●	○	●
Dynatest Mark IV		●		○

● — Excellent ○ — Good

Background

In 2002, the ACPA tested the performance of twelve profilers in Michigan and found that their reproducibility, and in come cases repeatability, was not sufficient for concrete construction quality control applications. *(1)* Profilers performed worst on test sections with coarse surface texture, and the problems were linked to the interaction of texture with the height sensor footprint of the candidate profilers. *(1-3)* Subsequently, Ames Engineering, Inc. offered a lightweight profiler with a modified height sensor footprint that was intended to improve repeatability on longitudinal tining. The ACPA tested the profiler's repeatability in October, 2003, and observed excellent performance on transverse tining and a smooth turf drag, and tremendous improvement on longitudinal tining. *(4)*

Since then LMI Selcom, a pervasive manufacturer of profiler height sensors, has offered a large-footprint height sensor for use on concrete surfaces with coarse surface texture. In addition, several profiler manufacturers offer large-footprint models that were either not available at the time of the original experiment or have been improved since then. The availability of new large-footprint options prompted the new round of tests reported here.

This document describes the testing of six large-footprint profilers on four pavements of diverse surface texture. The tests provided a basis for evaluating the performance of the six new candidate profilers on coarse-textured concrete pavement. The purpose of this experiment was to rate the repeatability of these profilers, and potentially qualify them as sufficiently repeatable for use on each type of concrete pavement surface. The qualification rating system is based on objective comparison of profile measurements, using the same analysis methods as in the original ACPA study. *(1, 5)* These analysis methods emphasize agreement in profile, rather than just the overall roughness index value. This eliminates cases in which the overall roughness may agree due to compensating error. Confidence in the measurement of profile is also needed for advanced applications, such as detection of localized roughness and diagnosis of potential paving problems from profile.

The Experiment

Profilers

Table 2 lists the six devices that submitted profiles for analysis, and provides a brief description of the footprint of each. The table also lists a abbreviation for each device used in summary tables throughout this report.

The SurPro 2000 was the only inclinometer-based device that participated in the experiment. It senses the pavement through direct contact by two supporting wheels, arranged in series 12 in (305 mm) apart. (See Figure C.1.) The device is pushed along a wheel path of interest by a walking operator, and it stores the average slope between the supporting wheels at regular distance intervals. (See Figure C.2.) This device provided data at a sample interval of 3.94 in (100 mm). Note that the SurPro 2000 is most often operated in a “reference profiler” mode, in which the wheel path of interest in clearly marked. That was not the case in this experiment.

The other five devices were inertial profilers that used non-contacting height sensors. Two of them were high-speed profilers, which are mounted on conventional highway vehicles (usually vans) and operate at conventional highway speeds. The other three were lightweight profilers, which are typically mounted on four-wheeled ATVs.

Table 2. Devices that submitted profiles.

Device	Footprint	Abbreviation
SurPro 2000	two supporting wheels	SurPro 2000
Surface Systems & Instruments, lightweight	RoLine height sensor	—
Ames Engineering, Inc., lightweight	TriODS laser system	Ames LW/TriODS
Ames Engineering, Inc., lightweight	RoLine height sensor	Ames LW/RoLine
Ames Engineering, Inc., high-speed	TriODS laser system	Ames HS/TriODS
Dynatest Mark IV	LMI Selcom, wide spot	Dynatest Mark IV

The developmental SSI lightweight profiler was fitted with a RoLine height sensor. (See Figure C.3.) This is a line sensor manufactured by LMI Selcom, which projects a line of laser light that is very narrow along one dimension and about 4 in (100 mm) wide along the other. On the SSI lightweight, the sensor was mounted so that the projected line formed a 45 degree angle with the direction of travel. (See Figure C.4.) This device provided data at a sample interval of 1 in (25.4 mm).[1]

The Ames Engineering lightweight profilers were both mounted to the same host vehicle. (See Figure C.5.) One of the profilers was fitted with the LMI Selcom RoLine height sensor, mounted so that the projected line was perpendicular to the direction of travel. The other profiler was fitted with the Ames TriODS laser system. This is an improved version of the profiler tested by the ACPA in October, 2003. Note that the simultaneous mounting of these two systems ensures that they will cover the same wheel path in each pass. The host vehicle also included an apparatus that helped the driver maintain an accurate and consistent lateral position during the tests. (See Figure C.6.)

The Ames Engineering high-speed profiler was mounted at the rear of a full-sized van. (See Figure C.7.) It was fitted with TriODS height sensors. All of the Ames Engineering profilers provided data at a sample interval of 0.1 ft (30.48 mm).

The Dynatest Mark IV high-speed profiler was mounted at the rear of an SUV. (See Figure C.8.) On the right side, it was fitted with a modified Selcom 5200 laser height sensor. This sensor has a footprint width of about 0.02 in (0.5 mm) and a footprint length (in the transverse direction) of 0.63 in (16 mm) at the typical stand off height.

[1]After the analyses were completed, SSI elected to withdraw their consent to use data from this device in the report.

Test Sections

The testing covered four pavement sections in central Iowa. The sections were primarily selected to cover a diverse range of surface texture, and included diamond ground concrete, transversely tined concrete, longitudinally tined concrete, and concrete with a light turf drag. The specific locations were, in part, sites of opportunity because they were all available within close proximity.

The diamond ground section was on I-35 northbound just north of U.S. 30 near Ames, Iowa. The measurements took place in the inside (passing) lane. The section was diamond ground to a depth of about 1/32 in (1 mm) over an original surface of transverse tining. The joint spacing was 20 ft (6.1 m), and the joints were skewed (1:6) with the right side forward. (See Figure C.9.)

The transversely tined, longitudinally tined, and light turf drag sections were all located along westbound County road E-57, west of Iowa 17. This was a two-lane undivided road in Boone County, Iowa just west of the town of Luther. All three sections existed within a 1.25-mile (2-km) stretch of pavement. The transversely tined section was west of Second Street and east of the entrance to a large grain elevator, and the longitudinally tined section was just west of the entrance. The light turf drag section was about 0.8 miles (1.3 km) west of the longitudinally tined section, at a low area within the grade.

All four of the test sections were straight (i.e., tangent).

The transversely tined section had “random” spacing that repeated on a 1 ft (0.3 m) interval. The spacing of individual troughs ranged from 5/8 to 1 1/2 in (22 to 38 mm). The joint spacing was 15 ft (4.6 m), and the joints were skewed (1:6) with the right side forward. The pavement had several quarter-sized popouts in its surface. (See Figure C.10.)

The longitudinally tined section had a uniform spacing of 3/4 in (19 mm) and a channel depth of 1/16 to 1/8 in (1.5 to 3 mm). (See Figure C.11.) This section was constructed in the fall of 2003. It had a joint spacing of 15 ft (4.6 m), and the joints were skewed (1:6) with the right side forward. These were single pass sawed joints that were roughly 5/16 in (8 mm) wide.

The light turf drag section was a very old pavement (more than 30 years) that was still in good condition, with the exception that several quarter-sized popouts appeared on the surface. This pavement had right angle saw cut joints, spaced 40 ft (12.2 m) apart.

Procedures

The experiment took place on October 11, 2005. All of the profilers visited the I-35 site first, and the group gained access to it at 9 AM. The profilers measured the diamond ground section in the following order: (1) the Dynatest Mark IV high-speed (2) the Ames Engineering high-speed, (3) the Ames Engineering lightweights, (4) the SurPro 2000, and (5) the SSI lightweight. These measurements were completed at 1 PM.

The diamond ground site was used for longitudinal distance measurement calibration. Two markings were placed 530 ft (161.5 m) apart, measured with a nylon-coated steel tape. Each profiler was able to use these markings for distance measurement calibration or verification in their first pass.

The sections on E-57 were tested between 12 PM and 4:20 PM. (The high-speed profilers proceeded to the E-57 site while other profilers were still on I-35.) Profilers occupied each section on E-57 in the same order as they did on I-35. In most cases, the E-57 test sections were measured one at a time. However, the transversely tined and longitudinally tined section fell within a short distance, so the Ames Engineering profilers covered both of them in the same sequence of passes. For most of the afternoon, one profiler made measurements on one or both of the tined sections while another measured the light turf drag section.

The transversely tined, longitudinally tined, and light turf drag sections were 523 ft (159.4 m), 528 ft (160.9 m), and 530 ft (161.5 m) long, respectively. The start and end of each section was marked with tape. However, the participants were not told the length of these sections.

Although the test section on I-35 was under a lane closure, the test sections on E-57 were opened to traffic. Since the road sustained about 100 vehicles per hour, many of them heavy trucks, flag men were posted at either end of the test sections while the lightweight profilers and the SurPro 2000 conducted measurements.

Only data from the right wheel path were requested. For this experiment, the right wheel path was defined as 36 in (914 mm) from the right lane edge stripe. However, this value was increased to 39 in (991 mm) on the diamond ground pavement to avoid the areas where two passes of the grinder overlapped. No markings were provided in the wheel path of interest. The Ames Engineering lightweight was operated with a vehicle-mounted guide to help maintain the proper lateral positioning within a lane.

Participants were encouraged to use their recommended practices. Of course, the ratings assigned to repeatability in this report are assigned not only to the device, but to the combination of device, measurement conditions, measurement procedures and operator proficiency. Operators chose their measurement speed. Some operators also elected to use automated triggering to initiate and terminate data collection.

Participants were required to provide data before leaving each site. Each participant was asked to make five profile measurements of each section. They did so, with the exception of the SurPro 2000 operator. The SurPro 2000 was a walking device with the ability to collect profile in either direction. As such, the operator measured profile on each return trip to the section start, and submitted either four or six profiles of each section.

Analysis

The primary concern of these tests was comparison of profiles, rather than summary index values. Comparison of the summary index values provides little information about the source of profile measurement problems. When only a small number of repeat measurements are available on a small number of sites, index values may agree because of compensating error. In contrast, study of the profiles reveals measurement problems with very few repeat measurements, and often provides useful diagnostic information when agreement is poor.

All of the profiles collected for this experiment were converted to a common file format. Although the segment starting and ending points were marked, the submitted profiles were not aligned perfectly. The longitudinal offsets between them were eliminated using automatic synchronization. *(1, 5)* To account for a small amount of longitudinal misalignment, all of the analyses reported here were conducted using 500 ft (160.9 m) of profile, beginning 14 ft (4.25 m) from the start of each test section.

Index Comparison

Table 3 provides the average IRI value measured by each device on each section. The overall group of inertial profilers did not reproduce each other's IRI measurements as well as might be expected. Further, the IRI values on the longitudinally tined section and the diamond ground section covered a much larger range, in terms of percentage, than on the other two sections. This is caused by differences in the way the footprint of these devices interacts with longitudinal textures. Individual IRI values are plotted in Appendix A.

Note that none of the five devices is necessarily deemed more correct than the others. That would require comparison to a carefully-selected reference measurement which is designed to define the elevation of the road surface under its footprint in a manner similar to a common vehicle tire. *(6)*

Table 3. Average IRI Values by Section.

Device	IRI (in/mi)			
	Grinding	Trans. Tining	Long. Tining	Turf Drag
SurPro 2000	48.2	138.9	76.7	85.9
Ames LW/TriODS	34.5	121.0	61.9	80.3
Ames LW/RoLine	30.7	123.2	63.2	81.0
Ames HS/TriODS	40.6	125.0	64.9	78.5
Dynatest Mark IV	33.3	128.9	66.0	80.9

Table 4 lists the coefficient of variation of the IRI values. (This is the standard deviation divided by the average.) This is a rough indicator of the repeatability of each device on each section. As a group, the profilers produced IRI values with the most scatter on the diamond ground section. The diamond ground section posed a difficult challenge to the profilers, because it has a longitudinal texture, which is more difficult to remove from the measurement by filtering. The section was also very smooth, and the depth of the texture is on the same scale as the height of longer wavelength features that are supposed to affect the IRI.

The scatter in IRI measurement was lowest on the transversely tined pavement and the pavement with a light turf drag. In the case of the transversely tined pavement, the profilers were able to average out the texture using a high sampling rate in the longitudinal direction. The light turf drag posed less of a challenge to the profilers because the texture was simply less aggressive than on the other sections.

Table 4. Coefficient of Variation of IRI Values by Section.

Device	**IRI, Coefficient of Variation (%)**			
	Grinding	Trans. Tining	Long. Tining	Turf Drag
SurPro 2000	9.6	2.8	4.4	3.4
Ames LW/TriODS	4.2	0.7	1.7	2.3
Ames LW/RoLine	1.6	0.5	0.9	1.2
Ames HS/TriODS	4.2	1.2	1.7	0.8
Dynatest Mark IV	2.7	2.2	3.4	2.7

Profile Repeatability

The main focus of this experiment was repeatability of profile measurement. Direct profile comparison is necessary in any study of the performance of profilers, because index values may compare favorably due to compensating error even when the profiles do not. Profile comparison will reveal these instances. An objective method of assessing profile agreement called cross correlation was used for this purpose. *(5)* A good rating by this method provides a reasonable expectation that the profiles and summary index values will agree on the same type of pavement in the field. This is because high correlation requires that the overall roughness is in agreement, as well as the details of the profile shape that affect the overall index value.

The cross correlation method provides a rating of agreement ranging from -100 to 100, where a value of 100 indicates perfect agreement. Any disagreement in overall roughness level or profile shape will degrade the value. The method can also be customized to emphasize the most relevant profile features. This is done by applying a filter to the profiles before they are compared. In this study, the output of the IRI filter was used as the main indicator of profile agreement.

Table 5 provides a summary of the cross correlation level observed for IRI filter output. In the table, the repeatability ratings are the average of all possible comparisons for a given profiler over a given road segment. For example, most of the profilers measured each section five times. This produced ten possible comparisons at each section. The average of the ten correlation values appears in the table.

Table 5. Average Cross Correlation, IRI Filter Output.

Device	**Repeatability Rating**			
	Grinding	Trans. Tining	Long. Tining	Turf Drag
SurPro 2000	30	81	76	85
Ames LW/TriODS	68	**99**	**93**	**96**
Ames LW/RoLine	**91**	**99**	**97**	**98**
Ames HS/TriODS	55	**97**	**91**	**96**
Dynatest Mark IV	83	**95**	87	**93**

The original ACPA study sought a value of 95 for repeatability of IRI filter output. *(1)* This is still considered the ideal benchmark for profiler repeatability. Nevertheless, a correlation level of 90 or higher indicates good agreement and a level of 95 or higher indicates excellent agreement. Any value of 90 or higher is shown in bold in Table 5.

The repeatability ratings in Table 5 are influenced by a combination of factors, including the type, shape, and depth of surface texture, the profiler footprint size and shape, the profiler filtering procedures, and the tracking behavior of the operator. In each set of repeat runs, three opportunities exist to prevent texture from compromising repeatability.

First, the profiler may sample at a very high rate (i.e., short interval) in the longitudinal direction, and apply low-pass filters to average out the texture. Obviously, this is most effective on transverse tining, or on isotropic textures, where the elevation varies rapidly in the longitudinal direction. (Isotropic textures vary the same way in any direction along the surface.)

Second, the profiler may sense the road surface with the large footprint. On longitudinal textures, such as longitudinal tining, diamond grinding, or drag textures, footprint width is critical. This is because a profiler with a narrow footprint may drift slowly over the troughs, and misinterpret them as long dips. Of course, the manner in which the elevation within the footprint is reduced to a single value is also very important.

Finally, the profiler operator must strive to pass over the same wheel path in each run. The best way to do this is to maintain a consistent distance from the lane edge or, in the case of longitudinal textures, travel in a path that is perfectly parallel with the texture. Maintaining a consistent lateral position also helps reduce the upward bias in roughness that may occur because of coarse texture. On longitudinal texture, this helps reduce the effect of drifting slowly over high and low areas within the texture. On transverse tining, this prevents changes in texture depth over the width of the pavement from contaminating the elevation values.

Table 5 shows that all of the profilers were least repeatable on the diamond ground pavement, and less repeatable on the longitudinally tined pavement than on the other two. This is because of problems in maintaining a consistent lateral tracking position, which compromise repeatability most on longitudinal textures. Further, the footprint, as defined by the combination of its width and averaging scheme, was not able to sufficiently reduce the effect of tracking variations in all cases.

The diamond ground section poses a more difficult challenge because it is so smooth, so any “noise” that appears in the measurement because of texture is more significant relative to the overall roughness. The only profiler that exhibited good repeatability on the diamond ground section was the Ames Engineering lightweight with the RoLine height sensors. Note that this height sensor’s footprint is 4 in (100 mm) wide. In addition, the Ames Engineering lightweight was operated with a lane tracking guide to help maintain a consistent distance from the lane edge.

The majority of the profilers exhibited excellent repeatability on the transversely tined section and excellent or good repeatability on the section with a light turf drag. On these sections, the most important factor in mitigating the effects of texture on profile measurement was a high sampling rate and proper low-pass filtering.

Tables 6, 7, and 8 examine the repeatability of long, medium, and short wavelength content of the profile for diagnostic purposes. This helps isolate the source of problems when the repeatability ratings for IRI filter output fall below 90. These wavelength ranges were isolated by filtering the profiles with four applications of a third order Butterworth filter; once high-pass in the forward direction, one high-pass in the backward direction, one low-pass in the forward direction, and one high-pass in the backward direction. This was done to cancel the phase shift associated with the filter. The cut-off values for the individual applications of each filter for the long, medium, and short wavelength ranges were 26.2 and 131.2 ft (8 and 40 m), 5.25 and 26.2 ft (1.6 and 8 m), and 1.05 and 5.25 ft (0.32 and 1.6 m), respectively.

Table 6. Average Cross Correlation, Long Wavelengths.

Device	**Repeatability Rating**			
	Grinding	Trans. Tining	Long. Tining	Turf Drag
SurPro 2000	61	85	73	84
Ames LW/TriODS	**90**	**97**	87	**97**
Ames LW/RoLine	72	**95**	77	**94**
Ames HS/TriODS	**95**	**99**	**95**	**99**
Dynatest Mark IV	**95**	**96**	**96**	**97**

Table 7. Average Cross Correlation, Medium Wavelengths.

Device	**Repeatability Rating**			
	Grinding	Trans. Tining	Long. Tining	Turf Drag
SurPro 2000	34	77	66	80
Ames LW/TriODS	81	**97**	**94**	**97**
Ames LW/RoLine	**91**	**98**	**95**	**98**
Ames HS/TriODS	69	**96**	**90**	**96**
Dynatest Mark IV	63	80	80	89

Table 8. Average Cross Correlation, Short Wavelengths.

Device	**Repeatability Rating**			
	Grinding	Trans. Tining	Long. Tining	Turf Drag
SurPro 2000	43	70	60	75
Ames LW/TriODS	49	84	70	78
Ames LW/RoLine	70	85	75	81
Ames HS/TriODS	36	79	65	69
Dynatest Mark IV	29	37	41	52

Tables 6 through 8 show that profilers are least repeatable in the short wavelength range. This is the range of wavelengths affected most by coarse texture. However, several profilers were able to obtain good or excellent repeatability for IRI filter output without repeatability ratings in the short wavelength range above 90. Note also that ASTM Standard E-950 places almost no emphasis on the correct measurement of short wavelength content. *(5)* Since it is the most common profile comparison method used for certification or profilers, innovations in profiler capability often focus on medium and long wavelength measurement.

Repeatability in the medium wavelength range was worst on the diamond ground section. The lack of repeatability was most likely caused by slow drift of the profilers across the ground-in troughs. The wavelength range that is contaminated by this effect depends on the width and spacing of the troughs and how quickly the profiler drifts from side to side. This may explain some of the low repeatability ratings for long wavelength content on the longitudinally tined section, where the spacing between the toughs is much larger. With a wider pattern, more travel distance is covered before the pattern is repeated, which corresponds to a longer wavelength.

Profile Reproducibility

Reproducibility is defined as the ability of one device to produce the same result as another. Thus, ratings of reproducibility can be calculated for any combination of two devices. Full matrices of reproducibility ratings are provided in Appendix B. These cover comparison of measurements from a given device to measurements of each of the other devices. Each table in Appendix B lists the results of these comparisons for a given site using a given filter type. Individual entries in the tables are the average correlation coefficient for all measurements of a site by one device compared to all measurements of the same site by another. Each device usually made five measurements, so an entry is really the average of twenty-five coefficient values. The diagonal entries in each table actually compare a device to itself, and are the repeatability values lists in Tables 5 through 8.

Reproducibility was poor overall, and worst on diamond grinding and longitudinal tining. This can be explained by (1) diversity in sensing technology and the treatment of narrow, downward profile features, (2) special difficulties posed by smooth concrete of coarse texture, and (3) differences in tracking behavior. For the short wavelength range, small differences in longitudinal distance measurement also affect the ratings.

The Ames Engineering lightweight profilers reproduce each other’s measurements more closely than any other pair of profilers, combination of profiler, because they were mounted to the same host vehicle. Note that the Ames high-speed also had TriODS sensors, but agreement between it and the Ames Engineering lightweight with RoLine sensors was 7 to 17 points lower. This roughly illustrates the penalty to repeatability that exists when the profilers are not on the same host vehicle.

This study did not seek to verify any of the profilers against a reference measurement. This is because a reference device has not yet been selected with a footprint or low-pass filtering practices that have demonstrated optimum relevance to vehicle response. *(6)*

Conclusions

The results of this study demonstrate that significant improvements are possible in profiler repeatability compared to the results of the 2002 ACPA profiler comparison study. All the inertial profilers included in the study exhibited good or excellent repeatability on a transversely tined pavement and a pavement with a drag texture. Further, in contrast to the 2002 experiment, a vendor was able to collect repeatable measurements on a longitudinally tined pavement, and demonstrated excellent repeatability with one type of height sensor and good repeatability with another. A smooth diamond ground pavement was the most challenging surface type to measure, and only one device demonstrated good repeatability on it.

Repeatability of profile measurement on longitudinally tined pavement and diamond ground pavement depended heavily on the use of a large height sensor footprint and consistent lateral tracking of the profiler.

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Appendix A: IRI Scatter Plots

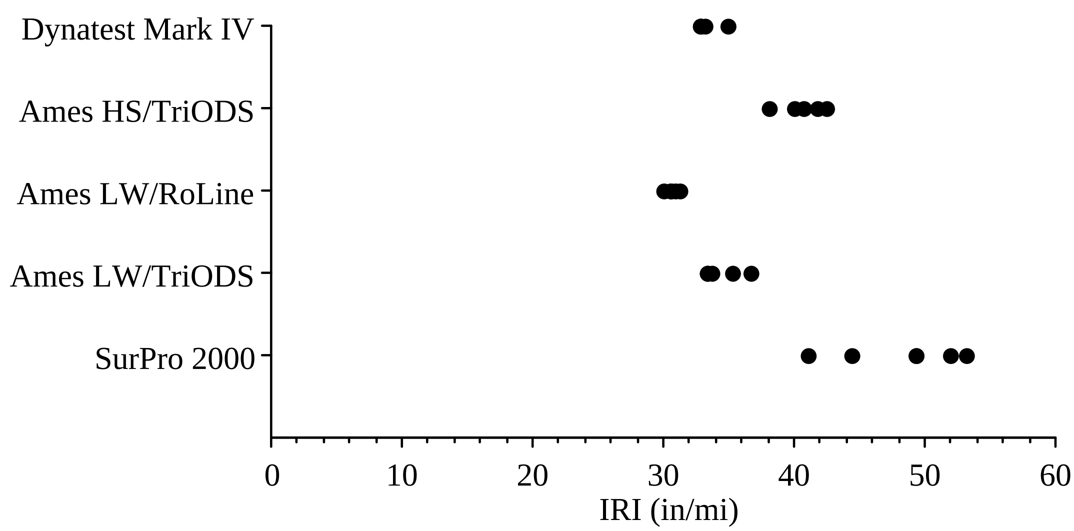

Figure A–1. IRI values measured on the diamond ground section.

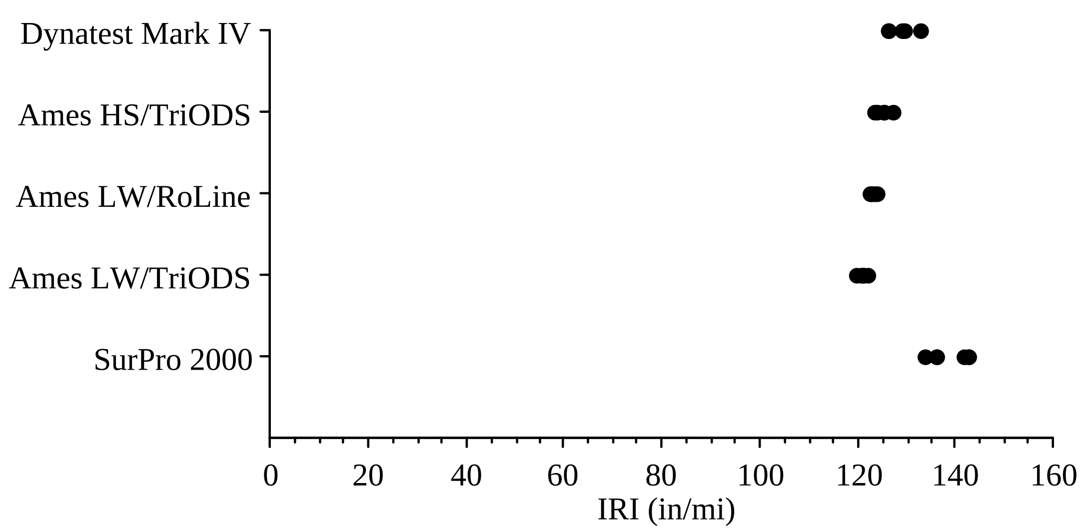

Figure A–2. IRI values measured on the transversely tined section.

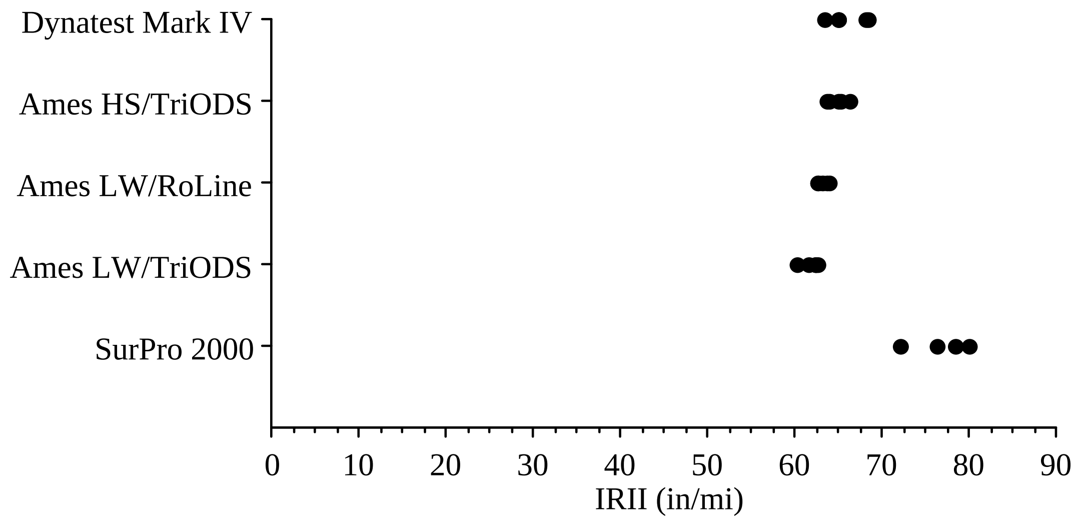

Figure A–3. IRI values measured on the longitudinally tined section.

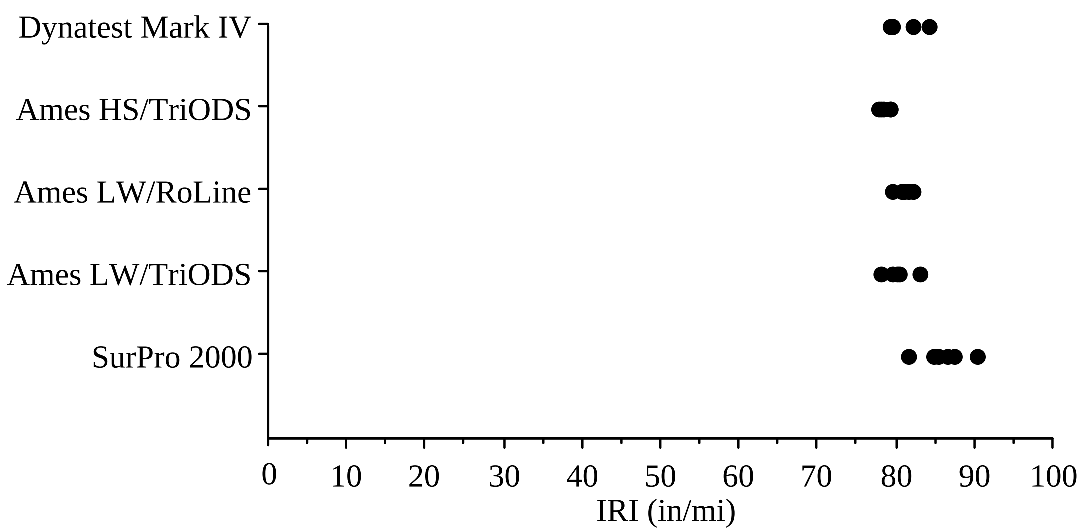

Figure A–4. IRI values measured on the light turf drag section.

Appendix B: Reproducibility Results

This appendix lists the results of cross correlation analysis performed on all of the profiles included in the study. Sixteen tables are provided, covering four wavebands and four test sections.

For each combination of filter and site, all of the measurements from a given device are compared to all of the measurements from the rest of the devices. Measurements from the device listed as the correlation reference are assumed to be correct, and measurements from the correlated device are compared to them. Measurements from the profiler listed as the "correlated" device are always interpolated to the sample interval of the correlation reference. As a result, comparison of two devices may produce a slightly different result, depending on which of them is designated the reference device and which is designated the correlated device. The table entries are often the average of twenty five values generated by comparing five repeat measurements by one profiler to each of five repeat measurements by another.

The diagonal entries in the tables provide a rating of repeatability, because they are the average of the correlation levels that result for all combinations of repeat measurements by the same device. These match the values provide in Tables 4 though 7.

Table B–1. IRI Filter, Diamond Ground Section.

Correlation Reference	**Correlated Device**				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	30	29	30	29	31
Ames LW/TriODS	29	68	71	52	70
Ames LW/RoLine	31	71	**91**	54	78
Ames HS/TriODS	29	52	54	55	54
Dynatest Mark IV	31	70	79	54	83

Table B–2. IRI Filter, Transversely Tined Section.

Correlation Reference	**Correlated Device**				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	81	65	67	61	63
Ames LW/TriODS	66	**99**	**97**	89	89
Ames LW/RoLine	67	**97**	**99**	**90**	**90**
Ames HS/TriODS	62	89	**90**	**97**	82
Dynatest Mark IV	63	89	**90**	82	**95**

Table B–3. IRI Filter, Longitudinally Tined Section.

Correlation Reference	**Correlated Device**				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	76	58	61	60	59
Ames LW/TriODS	58	**93**	**94**	81	84
Ames LW/RoLine	61	**94**	**97**	85	88
Ames HS/TriODS	60	81	85	**91**	85
Dynatest Mark IV	59	84	88	85	87

Table B–4. IRI Filter, Light Turf Drag Section.

Correlation Reference	**Correlated Device**				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	85	81	82	81	83
Ames LW/TriODS	82	**96**	**97**	86	**90**
Ames LW/RoLine	83	**97**	**98**	86	**91**
Ames HS/TriODS	81	86	86	**96**	89
Dynatest Mark IV	83	**90**	**91**	89	**93**

Table B–5. Long Wavelength Content, Diamond Ground Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	61	65	63	67	58
Ames LW/TriODS	65	**90**	78	**91**	78
Ames LW/RoLine	63	78	72	79	67
Ames HS/TriODS	68	**91**	79	**95**	79
Dynatest Mark IV	58	76	66	78	**95**

Table B–6. Long Wavelength Content, Transversely Tined Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	85	79	80	85	55
Ames LW/TriODS	80	**97**	**96**	**93**	66
Ames LW/RoLine	80	**96**	**95**	**93**	64
Ames HS/TriODS	85	**93**	**93**	**99**	66
Dynatest Mark IV	55	64	62	63	**96**

Table B–7. Long Wavelength Content, Longitudinally Tined Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	73	65	61	68	44
Ames LW/TriODS	65	87	82	**90**	53
Ames LW/RoLine	61	82	77	85	54
Ames HS/TriODS	69	89	85	**95**	60
Dynatest Mark IV	43	51	54	59	**96**

Table B–8. Long Wavelength Content, Light Turf Drag Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	84	86	85	88	72
Ames LW/TriODS	86	**97**	89	**91**	77
Ames LW/RoLine	85	89	**94**	**94**	79
Ames HS/TriODS	88	**92**	**94**	**99**	81
Dynatest Mark IV	72	77	79	81	**97**

Table B–9. Medium Wavelength Content, Diamond Ground Section.

Correlation Reference	Correlated Device SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	34	29	30	28	29
Ames LW/TriODS	31	81	82	73	80
Ames LW/RoLine	32	88	**91**	74	83
Ames HS/TriODS	29	67	68	69	68
Dynatest Mark IV	31	56	56	55	63

Table B–10. Medium Wavelength Content, Transversely Tined Section.

Correlation Reference	Correlated Device SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	77	64	64	62	57
Ames LW/TriODS	65	**97**	**98**	**91**	**92**
Ames LW/RoLine	66	**97**	**98**	**91**	**91**
Ames HS/TriODS	63	**90**	**91**	**96**	84
Dynatest Mark IV	58	79	80	73	80

Table B–11. Medium Wavelength Content, Longitudinally Tined Section.

Correlation Reference	Correlated Device SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	66	53	53	55	52
Ames LW/TriODS	55	**94**	**95**	88	86
Ames LW/RoLine	55	**94**	**95**	88	87
Ames HS/TriODS	56	86	87	**90**	83
Dynatest Mark IV	53	78	79	75	80

Table B–12. Medium Wavelength Content, Light Turf Drag Section.

Correlation Reference	Correlated Device SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	80	81	81	78	81
Ames LW/TriODS	82	**97**	**98**	85	**90**
Ames LW/RoLine	82	**97**	**98**	84	**90**
Ames HS/TriODS	80	87	86	**96**	**91**
Dynatest Mark IV	81	**90**	**90**	86	89

Table B–13. Short Wavelength Content, Diamond Ground Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	43	15	15	8	18
Ames LW/TriODS	21	49	51	40	56
Ames LW/RoLine	21	67	70	51	73
Ames HS/TriODS	11	34	35	36	39
Dynatest Mark IV	25	24	25	20	29

Table B–14. Short Wavelength Content, Transversely Tined Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	70	28	29	15	21
Ames LW/TriODS	34	84	83	51	76
Ames LW/RoLine	34	85	85	52	77
Ames HS/TriODS	18	54	54	79	56
Dynatest Mark IV	16	34	34	24	37

Table B–15. Short Wavelength Content, Longitudinally Tined Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	60	31	33	22	28
Ames LW/TriODS	39	70	70	49	63
Ames LW/RoLine	41	75	75	53	68
Ames HS/TriODS	28	45	46	65	56
Dynatest Mark IV	35	37	38	36	41

Table B–16. Short Wavelength Content, Light Turf Drag Section.

Correlation Reference	Correlated Device				
	SurPro 2000	Ames LW TriODS	Ames LW RoLine	Ames HS TriODS	Dynatest Mark IV
SurPro 2000	75	48	49	32	49
Ames LW/TriODS	61	78	79	45	69
Ames LW/RoLine	61	79	81	46	69
Ames HS/TriODS	40	54	55	69	64
Dynatest Mark IV	54	49	50	39	52

Appendix C: Photos

Figure C.1. SurPro 2000 close-up.

Figure C.2. SurPro 2000 operation.

Figure C.3. SSI lightweight inertial profiler.

Figure C.4. SSI lightweight inertial profiler, sensor arrangement.

Figure C.5. Ames Engineering lightweight inertial profiler, sensor arrangement.

Figure C.6. Ames Engineering lightweight inertial profiler operation.

Figure C.7. Ames Engineering high-speed inertial profiler.

Figure C.8. Dynatest Mark IV high-speed inertial profiler.

Figure C.9. Diamond ground section.

Figure C.10. Transversely tined section.

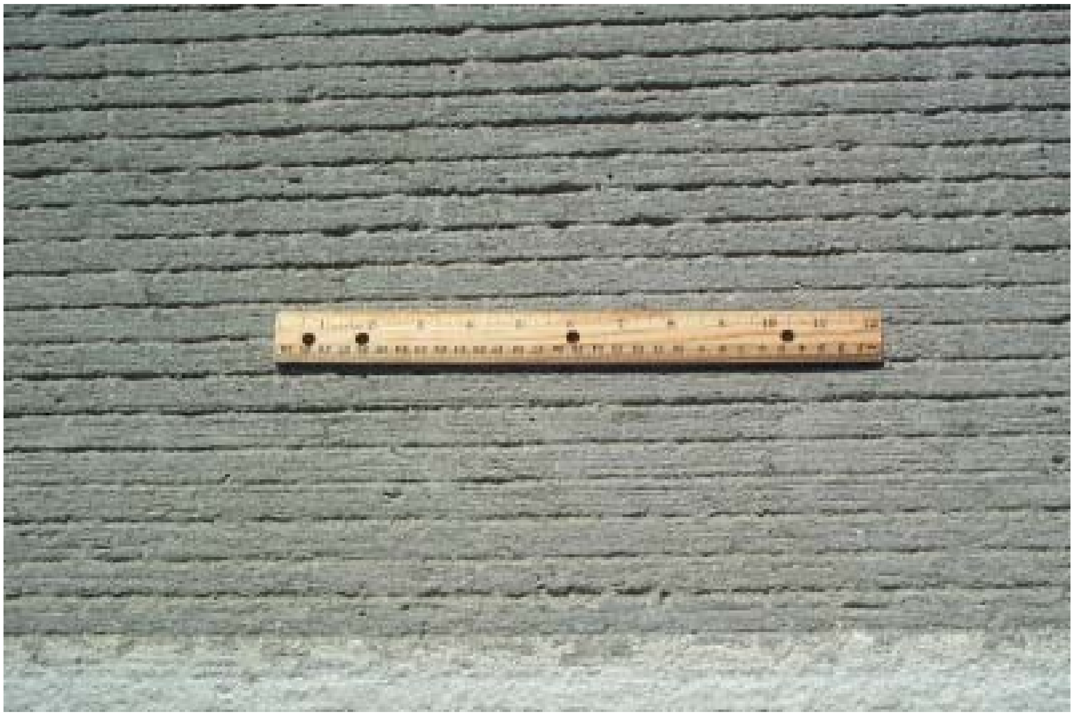

Figure C.11. Longitudinally tined section.

Figure C.12. Light turf drag section.