R&T UPDATE
Concrete Pavement Research & Technology

2005 ACPA Profiler Repeatability Tests

Manufacturers Continue to Improve Profiler Technology

Five new profilers were tested for repeatability 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 to 6 profiles on each section. Repeatability was quantified through objective comparison of profiles, using only those features that contribute to the IRI.

Ames Engineering's lightweight profiler with a RoLine height sensor demonstrated good or excellent repeatability on all four test sections. Ames Engineering's lightweight and high speed profilers, both using the TriODS laser system, demonstrated good repeatability on the longitudinally tined section and excellent repeatability on the transversely tined and drag texture sections. Dynatest's 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, where good is considered 90% or better, and excellent is considered 95% or better.

Table 1: Repeatability Classification

Device	Test Section			
	Grinding	Trans. Tining	Long. Tining	Drag Texture
ICC SurPro 2000				
Ames LISA w/TriODS *		●	○	●
Ames LISA w/RoLine *	○	●	●	●
Ames HSP w/TriODS		●	○	●
Dynatest Mark IV		●		○

● — Excellent ○ — Good

* Used Guidance Control

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 herein 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 laser sensor footprint and consistent lateral tracking of the profiler.

Background

In 2002, a study initiated by the Michigan Concrete Paving Association and ACPA tested the performance of twelve profilers in Michigan and found that their reproducibility and in some 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 laser height sensor footprint of the candidate profilers.[(1-3)] Subsequently, Ames Engineering, Inc. developed a lightweight profiler with a modified height sensor footprint that was intended to improve repeatability on longitudinal tining. ACPA tested the new profiler's repeatability in October 2003, and the profiler demonstrated excellent performance on transverse tining and smooth turf drag, and improvement on longitudinal tining.[(4)]

Since then LMI/Selcom, the primary manufacturer of laser profiler height sensors, has introduced a large-footprint height sensor for use on pavement smoothness profilers. In addition, several profiler manufacturers offer large-footprint models that were either not available at the time of the earlier experiments or have been improved since then. The availability of new large-footprint options prompted a new round of tests, which are summarized in this R&T Update.

The most recent tests provided a basis for evaluating the performance of the five 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 index may agree due to compensating error. Confidence in the measurement of profile is also needed for detection of localized roughness and diagnosis of potential paving problems from profile.

Profilers

The SurPro 2000 was the only inclinometer-based device that participated in the experiment. The other 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 others were lightweight profilers, which are typically mounted on four-wheeled ATVs.

Ames Engineering's lightweight profilers were both mounted to the same host vehicle. One of the profilers was fitted with the LMI Selcom RoLine height sensor (foot print 100mm x 1mm), mounted so that the projected line was perpendicular to the direction of travel. The other profiler was fitted with the Ames TriODS laser system (three-point laser).

The TriODS system was an improved version of the profiler tested by ACPA in October 2003. Note that the simultaneous mounting of these two systems ensured that they would 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.

Ames Engineering's high-speed profiler was mounted at the rear of a full-sized van and fitted with TriODS height sensors.

Dynatest's Mark IV high-speed profiler was mounted at the rear of an SUV. 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.

Test Sections

The four test sections, located in central Iowa, consisted of a diamond ground concrete, transversely tined concrete, longitudinally tined concrete, and concrete with a light turf drag. The four sections were chosen to provide a range of textures in order to better evaluate the equipment capability.

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 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 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 pavement had several quarter-sized popouts in its surface. 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). This section was constructed in the fall of 2003. The light turf drag section was a very old pavement (more than 30 years) that was still in good condition. Several quarter-sized popouts appeared on the surface.

The experiment took place on October 11, 2005. All of the profilers visited the I-35 site first, beginning at approximately 9:00 AM and finishing by 1:00 PM.

The sections on E-57 were tested between 12:00 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. 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.

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.

Did You Know?

- The range in IRI between the four devices on the diamond ground section was almost 18 in./mi.
- The range in PI (zero blanking band) between the four devices on the diamond ground section was almost 6 in./mi.
- The RoLine sensor can be used for 3D texture measurement as well as improving longitudinal texture measurement.

Test Results

Table 2 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.

Table 2: Average IRI Values by Section

Device	Grinding	Trans. Tining	Long. Tining	Turf Drag
ICC SurPro 2000	48.2	138.9	76.7	85.9
Ames LISA w/TriODS	34.5	121.0	61.9	80.3
Ames LISA w/Roline	30.7	123.2	63.2	81.0
Ames HSP w/TriODS	40.6	125.0	64.9	78.5
Dynatest Mark IV	33.3	128.9	66.0	80.9

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]

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 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.

The main focus of this experiment was repeatability of profile measurement. 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. A rating of 90 or 95 means that a profiler can be expected to provide IRI values within 10% or 5%, respectively, on multiple runs over the same type of pavement

Table 3 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.

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 3.

The repeatability ratings in Table 3 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.

Table 3: Avg. Cross Correlation, IRI Filter Output

Device	Grinding	Trans. Tining	Long Tining	Turf Drag
ICC SurPro 2000	30	81	76	85
Ames LISA w/TriODS	68	**99**	**93**	**96**
Ames LISA w/Roline	**91**	**99**	**97**	**98**
Ames HSP w/TriODS	55	**97**	**91**	**96**
Dynatest Mark IV	83	**95**	87	**93**

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 drag textures.

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 3 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 compromises 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 posed a more difficult challenge because it was so smooth that any "noise" in the measurement because of texture was more significant relative to the overall roughness.

The results of this study show that a 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. Repeatability results on longitudinally tined and diamond ground pavement, while having improved significantly, indicate that further development work is required by some profiler manufacturers.

For more information, see Reference 6, available at www.pavement.com.

References

1. Karamihas, S. M. and T. D. Gillespie, "Assessment of Profiler Performance for construction Quality Control: Phase I," Portland Cement Association, *PCA R&D Serial No. 2877* (2005) 61 p.

2. Karamihas, S. M., "Assessment of Profiler Performance for Construction Quality Control with Simulated Profilograph Index." *Transportation Research Record 1900* (2004) pp. 12-18.

3. Karamihas, S. M., "Assessment of Profiler Performance for Construction Quality Control." Transportation Research Board Paper 04-4103 (2004).

4. American Concrete Pavement Association, *Research and Technology Update Number 5.01* (January 2004) 4 p.

5. Karamihas, S. M., "Development of Cross Correlation for Objective Comparison of Profiles." *International Journal of Vehicle Design*, Vol. 36, Nos. 2/3 (2004) pp. 173-193.

6. Karamihas, S. M., "Critical Profiler Accuracy Requirements." *University of Michigan Transportation Research Institute Report UMTRI-2005-24* (2005) 115 p.

ACPA
AMERICAN CONCRETE PAVEMENT ASSOCIATION
5420 Old Orchard Road, Suite A100, Skokie, IL 60077
Tel.: 847.966.2272; Fax: 847.966.9970; www.pavement.com