R&T UPDATE
Concrete Pavement Research & Technology

THE INTERNATIONAL ROUGHNESS INDEX (IRI):
WHAT IS IT? HOW IS IT MEASURED? WHAT DO YOU NEED TO KNOW ABOUT IT?

Recent surveys by the National Partnership for Highway Quality (NPHQ) and the Federal Highway Administration (FHWA) have shown that the primary concern for the motoring public is road condition, or pavement smoothness. Currently, most state Departments of Transportation (DOT's), as well as many county and municipal agencies measure pavement smoothness on pavement rehabilitation and construction projects. The most common smoothness measuring device for construction acceptance on new concrete pavements has historically been the California profilograph. Recently, some states have been looking at different smoothness measurement devices, so that the data reported is compatible with pavement management system (PMS) data.

What is IRI?

Since 1990, the FHWA has required the state DOT's to report road roughness from their PMS on the International Roughness Index (IRI) scale for inclusion in the Highway Performance Monitoring System. The IRI is a profile-based statistic that was initially established in a study by the World Bank. It is used worldwide as the index for comparing pavement smoothness. However, IRI is not currently in common use for construction acceptance.

The IRI is developed mathematically to represent the reaction of a single tire on a vehicle suspension (quarter-car) to roughness in the pavement surface (Figure 1), traveling at 50 mph (80 km/h). The algorithm of the quarter-car simulation is very complex and is found in the appendix of ASTM E 1364.

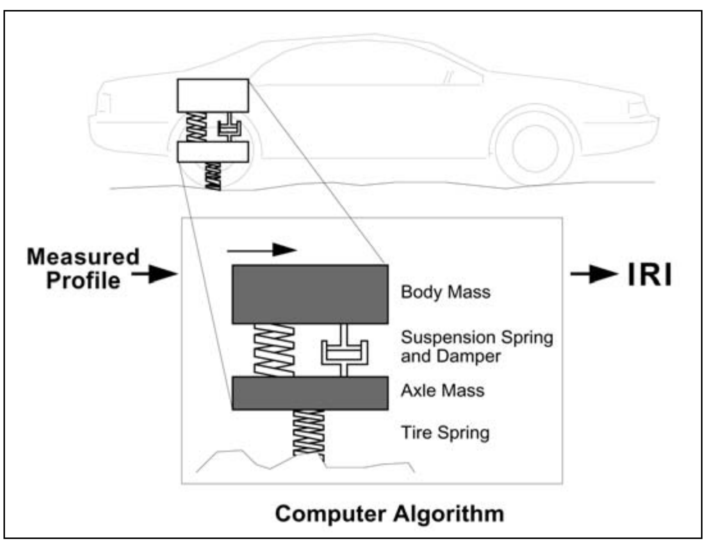

Figure 1. Quarter-car simulation of road roughness

The quarter-car model used in the IRI algorithm is just what its name implies: a model of one corner (a quarter) of a car. The model is shown schematically in Figure 1: it includes one tire, represented with a vertical spring, the mass of the axle supported by the tire, a suspension spring and a damper, and the mass of the body supported by the suspension for that tire. IRI, like the Profile Index (PI) from California profilographs, is expressed in inches/mile (mm/km).

The quarter-car simulation is meant to be a theoretical representation of the response-type systems in use at the time the IRI was developed. It is tuned to maximize correlation with response-type road roughness measuring systems such as the Mays Ride Meter, the PCA meter, and the Cox meter.

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IRI is linearly proportional to roughness. If all of the elevation values in a measured profile are increased by some percentage, then the IRI increases by exactly the same percentage. An IRI of 0.0 means the profile is perfectly flat. A value of 180 in/mi is often used by state DOT's as a trigger for resurfacing highways. There is no theoretical upper limit to roughness, although pavements with IRI values above 500 in/mi (8 m/km) are nearly impassable except at reduced speeds.

Measurement of IRI
Most agencies collect PMS data (reported in IRI) using high-speed vans equipped with lasers, accelerometers, and computer equipment to measure the profile of roads in the network. This equipment measures surface profiles at traffic speeds and provides excellent results for network analysis in pavement management systems. However, because these devices are mounted to a full-size van, automobile, or trailer, they are too heavy to be used on the roadway within hours of concrete placement. Therefore, they are not effective for providing feedback to the contracting crew. Additionally, there is no direct relationship between results from vehicle-mounted profilers to results from profilographs or other quality control-friendly equipment.

The newest equipment, lightweight surface profilers, uses non-contact technology similar to the larger profilers. Lightweight profilers blend the ability to get on a pavement within hours of placement with speed and the ability to compute an array of profile indices. A number of agencies have begun to employ or investigate lightweight profilers.

Lightweight profilers use non-contact, computer-based systems to develop a surface profile. The equipment is mounted to a small, motorized cart and is capable of measuring the surface at speeds ranging from 3-25 mph (5-40 km/h), depending upon the manufacturer. A basic system contains an accelerometer, non-contact height sensor (laser), computer, display, and printer. Measurements are independent of weather conditions (temperature, sunlight, wind).

As the profiler moves along the pavement, the onboard accelerometer gives the computer data necessary to calculate changes in vertical position of the vehicle body. The laser measures the distance between the vehicle body and the roadway surface. All of this information is stored in the computer at regular intervals. Once a run is complete, or in real-time, the information is summarized using a roughness statistic.

Most of the available systems quickly produce the two most common profile indices (Profile Index, International Roughness Index). Inputs from the accelerometer and laser sensor are fed to the onboard computer, which calculates and stores the pavement profile. The equipment should meet ASTM E950 Class I requirements for use on highway pavement.

There are several advantages to the lightweight profilers, including:

- Higher speed operation than some devices
- No set-up or breakdown required
- Acceptable for early use on concrete

Lightweight profiler disadvantages include:

- Higher cost compared to profilographs
- Questionable accuracy on projects with deep tining textures and recessed or open joints

IRI Accuracy: Bias, Repeatability, Reproducibility
With the increased interest in profilers and IRI, and the desire to have smoothness data at construction comparable to pavement management data, questions have been raised about the accuracy of the IRI statistic, based on the profile measurements of current devices and the mathematical algorithms used to process the data, specifically with regard to concrete pavements. Recent studies and comparison of data sets have shown inconsistencies in IRI results. These inconsistencies fall into three categories:

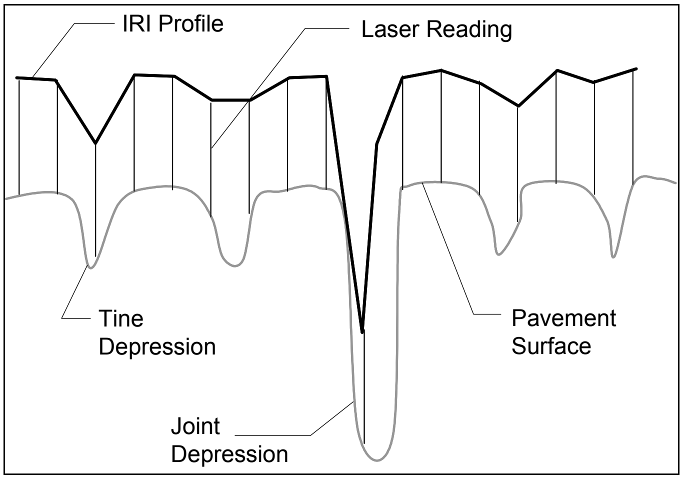

Figure 2. Effect of surface texture and joints on elevation readings of laser

bias, random error, and disagreement between devices.

Bias refers to the fact that the measurement capabilities of profilers may be biased toward asphalt and against concrete. This argument is based on the fact that concrete pavements are given a "roughened" surface texture when constructed, and asphalt pavements are rolled smooth. Most concrete pavements also have sawed joints at regular intervals. The shots of the laser, mounted on the profiler to determine roadway surface elevation, may fall into grooves or low spots imparted to the surface by the texturing operation. The laser readings might also fall into a sawed joint (Figure 2). The algorithms used to develop IRI results do not properly account for these "non-roughness" effects. A bridging filter is needed to avoid this source of error.

Data obtained from the Minnesota DOT, which was compiled from the Mn/DOT pavement management system, shows an example of how IRI statistics developed from current profiler data may be erroneous. Mn/DOT owns two different pavement management vans and tested them on the same stretches of roadway, portions of which were concrete and portions asphalt. Mn/DOT also took a panel of judges over the same stretches of roadway and had them rate both the asphalt and the concrete sections. Figure 3 shows the data from one of the profilers. Note that for the higher-rated (smoother) pavements, the concrete sections had a higher IRI than the asphalt sections. The same trend also shows up in Figure 4, which plots the results from a different Mn/DOT profiler.

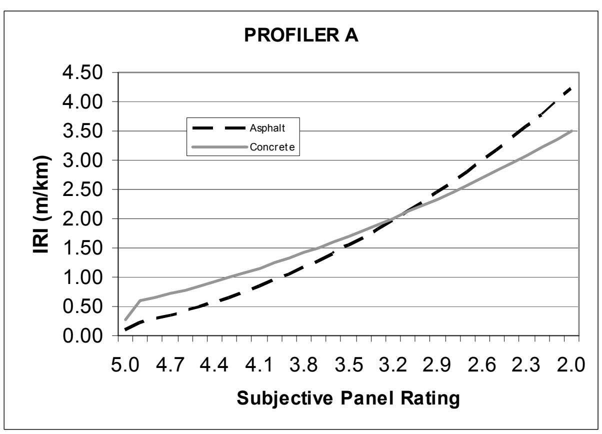

Figure 3. Bias of Profiler A; IRI vs. Panel Rating

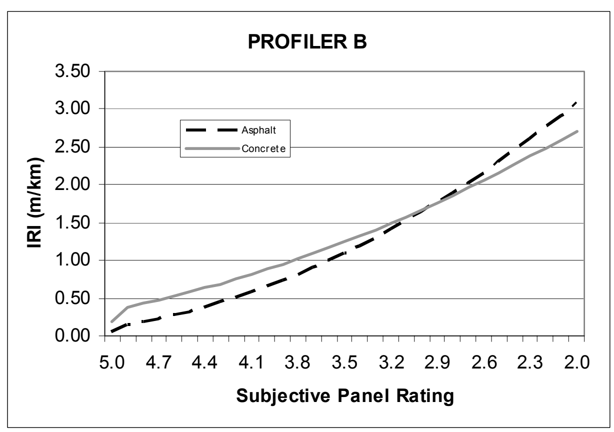

Figure 4. Bias of Profiler B; IRI vs. Panel Rating

Repeatability refers to the ability of one machine to get the same result on the same stretch of roadway in two different passes. If the shots of the laser in the second run do not match up with the shots from the first, the "surface trace" could be different (see Figure 5). This of course assumes that the profiler is working correctly and is taking elevation readings at the same distance between shots of the laser. Because concrete surfaces are uniformly specified (i.e. tining and joints are typically uniformly spaced), the surface is not necessarily random and the profile data may not average out over a segment.

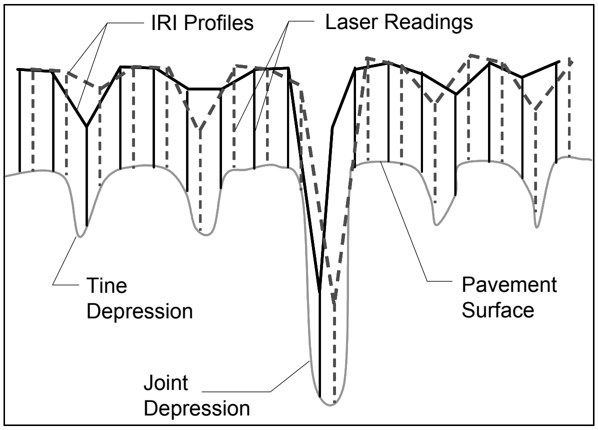

Figure 5. Difference in surface readings
due to different laser startup

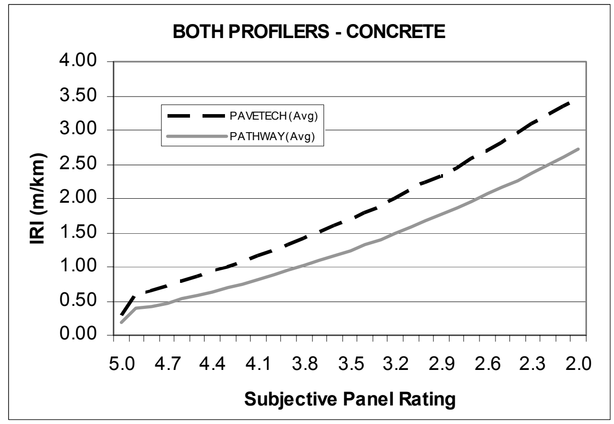

Figure 6. Difference between two profilers
on same test section, after calibration

Reproducibility refers to the ability of two machines to get the same result on the same stretch of roadway. Some profilers, whether same manufacture or different, do not produce identical results, even after calibration on the same stretch of roadway. A recent study[(4)] of lightweight inertial profilers, initiated by FHWA in an effort to examine the possibility of standardization, concluded that there was insufficient reproducibility between the devices tested to recommend using them for construction acceptance. Figure 6 plots data from the Minnesota DOT showing the results of consecutive runs of different profilers, after calibration to the same stretch of roadway.

Summary

The International Roughness Index is a roadway roughness statistic widely used for pavement management, and its use in pavement construction is on the rise. The IRI of a specific stretch of pavement is calculated using a mathematical algorithm and pavement smoothness data obtained with a profiler. Profilers use non-contact technology such as lasers to approximate the elevation of the pavement as the measurement vehicle travels across the surface.

There are currently a few concerns regarding IRI developed from the profile data of current profiler equipment, such as bias against concrete and dependability of the results. These concerns may be alleviated in the future with development of new technology, improved production, and standardization of profilers. Research sponsored by ACPA is currently underway to attempt to improve the equipment and indices with regard to known problems with bias, repeatability, reproducibility, and bridging of "non-roughness" surface effects such as tining and joints. Until these improvements become standard, use of the better-known California profilograph is recommended for construction acceptance.

References

1. Sayers, M.W. and S.M. Karamihas. *The Little Book of Profiling,* University of Michigan Transportation Research Institute, September 1996. Downloaded from www.umtri.umich.edu/erd/roughness.

2. Sayers, M.W. "On the Calculation of International Roughness Index from Longitudinal Road Profile," *Transportation Research Record 1501*, 1995, pp 1-12.

3. Minnesota Department of Transportation, PMS data, obtained from Fred Maurer, 1997.

4. Swanlund, M.E. and D. Law. "Demonstration of Lightweight Inertial Profilers for Construction Quality Control: Status Report," 7th International Conference on Concrete Pavements, Orlando, FL, Sept. 2001.

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