Introduction to the International Roughness Index

Bituminous Smoothness Training Workshop
April 11, 2007
IT’S A FACT:

Many customer surveys, on both a national and local level, have shown us that *Pavement Smoothness* is one of the main factors when it comes to rating the nation’s highways.
Pavement Smoothness = Ride Comfort

Q: How comfortable is this road to drive on?
Ride Comfort Depends on:

- Human Response to Vibration
- Vehicle Response to the Road
- Road Roughness
Human Response to Vibration

- Vital organs in the abdominal cavity resonate at about 5 Hz
- A human head resonates at about 25 Hz
- Human eyes resonate at 30-80 Hz
- It is tough to grip a steering wheel if it is moving at 50-200 Hz
Human Response to Vibration
Body Bounce and Axle Hop
Vehicle Response to the Road

Gain

Frequency (Hz)

Pickup

Sedan
IRI Sensitivity

![Graph showing IRI sensitivity with peaks at Body Bounce (1-2 Hz) and Axle Hop (10-12 Hz)]
True of False?

The California Profilograph doesn’t accurately determine the riding comfort of a roadway.

TRUE
“No claim is made that the roughness or riding quality of a pavement is directly or completely reflected by the profile index.”

“It should again be emphasized that strictly speaking, the devices reported herein do not furnish a direct index to “riding qualities.”

Francis N. Hveem, 1960
(inventor of the California Profilograph)
Why doesn’t the Profilograph measure and P.I. reflect the “Riding Comfort” of a roadway?
How many Minnesotans drive a vehicle with a 25-foot wheelbase?
The California Profilograph

Because it’s front and rear wheels are in contact with the pavement surface, the profilograph cannot accurately measure the pavement profile.

Actual Profile

½ Device Length

Profilograph Trace
Some of the roughness that hides inside the 0.2” blanking band causes drivers to experience roughness.
Result:

Ride Incentives have been paid on new pavement surfaces that the public does not consider to be smooth.
A smoothness index should be...

**Time Stable**
- Does not change with time

**Transportable**
- Compatible with different profiling methods

**Valid**
- Same result regardless of hardware

**Relevant**
- Reflect what road users experience
Response Type Road Roughness Measurement Systems

1941

The BPR Roughometer

1960's

A car with a Mays meter. Similar to PCA Roadmeter
Average Rectified Slope (ARS)

Average Rectified Slope = The ratio of the accumulated suspension motion of a vehicle (in, mm, etc) divided by the distance traveled by the vehicle during the test (mi, km, etc.).

ARS = 60 inches/mile
Average Rectified Slope (ARS)

ARS = 100 inches/mile

ARS = 50 inches/mile

ARS = 50 inches/mile
Problems with “Response Type” devices

- Hard to get the same results twice
  - Tire Size, Type, and Pressure
  - Shocks/Springs (change over time)
  - Driver
  - Mechanical
Measuring Pavement Profiles

1. Reference elevation = instrument height

2. Height relative to reference = rod

3. Longitudinal distance measured with tape or laser
Inertial Profiler

1. Inertial Reference: A
2. Height relative to reference (laser, infrared, or ultrasonic sensor)
3. Speed/Distance pick-up

Accelerometer: A
Inertial Profilers in Minnesota

These devices do not measure the IRI. They measure the pavement profile.
Inertial Profiler Components

- **Accelerometer** (reference elevation)
- **Laser Height Sensor** (height relative to reference)
- **Distance Measuring Instrument** (longitudinal distance)
Accelerometers

Accelerometers are used in a wide variety of machines, specialized equipment and personal electronics including seismology equipment, car alarm systems, and crash detection/air bag deployment sensors.

In profilers, they measure the movement of the vehicle body which is then removed from the height sensor readings to yield the pavement profile.
Laser Height Sensor

The laser height sensors measure the distance from the reference plane to the pavement surface. They operate around 16KHz. At 60 mph they can take about 15 readings per inch of vehicle travel.
Lasers take a reading about every 1/16-inch as the van drives down the road at highway speeds.
Triods Laser
Typical Profile Measured with an Inertial Profiler
Profiles from inertial devices and static devices do not look the same.
After filtering out the long wavelengths (> 300 ft) from the static device
The IRI was first recommended as a standard for roughness measurements at the International Road Roughness Experiment conducted in 1982.
International Road Roughness Experiment

- Sponsored by the World Bank
- Held in Brasilia, Brazil, in 1982.
- Researchers from Brazil, England, France, and the US
- Reference Average Rectified Slope (RARS)

- Their recommendation was that the $\text{RARS}_{80}$ ($\text{RARS} @ 80 \text{ km/hr}$) was the best numerical index and came to be known as the International Roughness Index, or IRI
Definition of IRI

The International Roughness Index (IRI) is a scale for roughness based on the simulated response of a generic motor vehicle to the roughness in a single wheel path of the road surface.

It’s true value is determined by obtaining a suitably accurate measurement of the profile of the road, processing it through an algorithm that simulates the way a reference vehicle would respond to the roughness inputs, and accumulating the suspension travel.

It is normally reported in inches/mile or meters/kilometer
$RARS_{80} = IRI$

When the ARS is calculated using the Quarter-Car Simulation @ 80 km/hr, it is known as the $RARS_{80}$, or International Roughness Index.
The computer code for calculating IRI from a measured profile is contained in a subsequent report published in 1986.
The IRI is the property of a “single” wheel track.
IRI Particulars

1. Calculated at 80 km/hr (49.7 mph) to cover the same wavelengths that affect road using vehicles.
   - Fast speeds are effected most by long wavelengths
   - Slow speeds are effected most by short wavelengths

2. Sensitive to the range of wavelengths detectable by most road users (4 to 100 feet).

3. Maximum sensitivity to the most objectionable wavelengths, body bounce (~50 ft) and axle hop (~7 ft)
IRI Filtering

The IRI filters the raw profile in two ways:

1. 250mm (9.8”) moving average filter is applied
2. The Quarter-Car (Golden Car) filter is applied
A moving average filter ("low-pass" filter)

For IRI, B=250mm (9.8")
(represented as the way a tire envelops the ground)
Quarter Car Filter

Measured Profile

Body Mass
Susp Spring and Damper
Axle Mass
Tire Spring

Computer Algorithm

IRI

150 inches/mile
Justification for choosing the IRI

1. Defined by a mathematical function of the longitudinal profile rather than by a piece of equipment (time stable).

2. Compatible with both manual profile measurement methods and high speed methods of data collection (transportable).

3. Reflects the roughness that affects the driving public (relevant).

4. The same index is generated regardless of the hardware when applied to the same road (valid).
### FHWA IRI Categories

<table>
<thead>
<tr>
<th>Roughness Category</th>
<th>IRI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inches/mile</td>
</tr>
<tr>
<td>Good</td>
<td>&lt; 95</td>
</tr>
<tr>
<td>Acceptable</td>
<td>&lt; 170</td>
</tr>
</tbody>
</table>

Average IRI on Minnesota Interstates = 87 in/mi  
Average IRI on Minnesota Non-Interstates = 105 in/mi  
About 8% of the state highway miles are >= 170 in/mi
IRI the year after Overlay
(3-4” Overlays done in 2004)

Even pay for a 2-lift overlay
Who uses IRI?

- Mn/DOT has measured IRI on the state highway system every year since 1993.

- Nearly every state DOT measures IRI on their system.

- FHWA has required states to measure IRI on the National Highway System every year since 1993 (the results are reported to Congress).

- The use of IRI for construction acceptance is new.
Bumps

A roadway which is otherwise very smooth will generate complaints if there is a single event that causes the driver to be uncomfortable.
Reporting IRI by Segments

65 in/mi
63 in/mi
77 in/mi
53 in/mi

528 foot intervals

BUMP
Reporting Continuous IRI

Slide this frame one data point at a time. Calculate the resulting IRI in inches/mile.

25 foot interval
If this…

ARS = 1 inch/25 feet

continued for an entire mile…

ARS = 211 inches/mile
Gervais Avenue in front of Maplewood Lab

IRI = 200 in/mile
961 inches/mile!
FHWA’s
“ProVal” Profile Analysis Software

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Your Resource for Smoothness

ProVAL
ProVAL (Profile Viewing and Analysis) is an engineering software application that allows users to view and analyze pavement profiles in many different ways. It is easy to use and yet powerful to perform many kinds of profile analyses. ProVAL is a US Department of Transportation, Federal Highway Administration (FHWA) product that is continuously updated and improved.

FHWA NE/UDOT PMS ProVAL Workshop
This workshop was held on November 3, 2005 in New Brunswick, New Jersey, USA. View the photo gallery.

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Summary

• The California Profilograph & Profile Index do not reflect the “riding comfort” of a roadway.

• The IRI is tuned into the wavelengths that cause humans to feel discomfort (body bounce & axle hop).

• IRI can be calculated from any accurately measured pavement profile. This means you cannot calculate the IRI from a profilograph trace.

• Continuous IRI can be used to locate isolated roughness (i.e. bumps & dips) and will be used in future Mn/DOT specifications.
Any Questions?