55th ACPA Annual Meeting
Concrete Pavement University, Session 3

Urban and Low-Speed Road Roughness

November 29, 2018
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Outline

• Measurement Issues
• Special Content
• IRI at Low Speed
Outline

• Measurement Issues
  – Inertial profilers
  – Low speed
  – Braking
  – Stops

• Special Content

• IRI at Low Speed
Inertial Profiler

\[ Z_{Road}(x) = Z_{Ref}(x) - \left( Z_{Ref}(x) - Z_{Road}(x) \right) \]

Accelerometer Alignment, Servo Type

\[ A_{ZF} + g \]

\[ Z_E \]

\[ X_I \]

\[ A_{XI} \]

\[ A_{ZV} = A_{XI} \sin(\theta) + (A_{ZF} + g) \cos(\theta) - g \]

\[ A_{ZV} - A_{ZE} = A_{XI} \sin(\theta) + (A_{ZF} + g)(\cos(\theta) - 1) \]

Tilted due to longitudinal deceleration

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Low Speed Operation, Roughness Profiles

Left IRI (in/mi)

- 45 mph
- ~3 mph (idle)

Distance (ft)
Braking, Filtered Elevation

Right Elevation (in)

Distance (ft)

Constant Speed

With Braking
Braking, Roughness Profiles

Right IRI (in/mi)

- Constant Speed
- With Braking

Distance (ft)
Stop-and-Go Operation

Speed (mi/hr) vs. Distance (ft)
Stop-and-Go Operation, Roughness Profile

Left IRI (in/mi)

Distance (ft)

- No Stop
- 3rd Oder Butterworth
- Moving Average
Short-Term Recommendations

Individuals:

• Find the limits for your profiler.
• Teach your operator to identify areas of invalid operation.

The Community:

• Find the limits for each profiler design.
• Teach profilers to identify areas of invalid operation automatically.
• Exclude invalid areas from roughness statistics.
Outline

• Measurement Issues

• Special Content
  – Built-In Features
  – “Wavy” Roads (deferred)

• IRI at Low Speed
Roughness Profiles

Left Elevation (in)

High-pass filtered (100 ft)

Left Roughness Profile (in/mi)

25-ft base length

Distance (ft)
Built-In Features

![Graphs of Left Elevation and Left Roughness Profile](image)

Left Elevation (in)

Pass 3
Pass 2
Pass 1

Left Roughness Profile (in/mi)

Pass 1
25-ft base length

Passes 2 and 3

Distance (ft)
Built-In Features

Right Elevation (in)

Drainage Inlets

Bridge Joint

High-pass filtered (20 ft)

Right Roughness Profile (in/mi)

25-ft base length

Distance (ft)
Built-In Roughness: Compound Event
Built-In Roughness: Compound Event

Right Elevation (in)

High-pass filtered (100 ft)

Utility Cover
Crowned Intersection
Ped. Crossing
Ped. Crossing
Sunken Utility Cover

Right Roughness Profile (in/mi)

10-ft base length

Distance (ft)

4780 4800 4820 4840 4860 4880 4900 4920

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Outline

• Measurement Issues
• Special Content
• IRI at Low Speed
Golden Car Model

\[ C = c_s/m_s = 6.0 \text{ sec}^{-1} \]
\[ K_1 = k_t/m_s = 653 \text{ sec}^{-2} \]
\[ K_2 = k_s/m_s = 63.3 \text{ sec}^{-2} \]
\[ \mu = m_u/m_s = 0.15 \]
\[ B = 9.84 \text{ in} \]

Changing Speed.....

• changes which aspects of the road surface are important. (A)
• alters the rank order of pavements. (A)
• changes the relationship between “in/mi” and vibration intensity. (B)
• changes which aspect of vehicle response is most important. (C)
General’s Highway, Sequoia and King’s Canyon National Park, CA
(A) Low-Speed Road Content......
(B) Golden Car Model Gain (Linear Scaling)

Karamihas, S. M., “Golden-Car Simulation Speed and Its Implications to the Relevance of the IRI.”  
Correlation to Measured Acceleration
Task 16
Ride and Profile Measurement on PCC

Seat BTZ Vertical Accel. (g²/Hz)

Frequency (Hz)

Important Findings

• IRI and measured ride discomfort were correlated.

• Matching simulation speed to travel speed improved correlation.

• Customizing the model improved correlation further.

• On urban pavements, localized roughness (i.e., transient vibration) was as important as overall roughness.

\[
\begin{align*}
C &= c_s/m_s = 6.0 \text{ sec}^{-1} \\
K_1 &= k_t/m_s = 653 \text{ sec}^{-2} \\
K_2 &= k_s/m_s = 63.3 \text{ sec}^{-2} \\
\mu &= m_u/m_s = 0.15 \\
B &= 9.84 \text{ in}
\end{align*}
\]
Transient Events/Localized Roughness

MTV/RMS weighted vertical accel., seat/buttock interface (-)
Thank you.