Achieving High Correlations of Inertial Profilers with Reference Profilers at the Smart Road

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Objectives

- State DOTs want to certify Inertial Profilers using ASTM E950 which requires 94% IRI Cross Correlation of candidate Inertial Profiler with Reference Profiler.
- Reference profiler must provide 98% Accuracy and Repeatability Cross Correlation profiles.
- A Certification Site must be established that supports High Cross Correlations—Smart Road?
- Train Operators—Reference Profiler Rodeo!
- Finally, need to Devise Strategies to Achieve High Cross Correlations with Inertial Profilers.
May 2014
Reference Profiler Rodeo

1. **Provide Operator Training** to Reference Profiler Operators
2. **Provide Certification Site Training** to Reference Profiler Operators
3. **Compare Profiles Collected by Reference Profilers** from different State DOTs with different operators
Classroom Operator Training

- General Description of SurPRO Instrument
  - General Arrangement, sensors and electronics
  - Basic Theory and Method of Data Acquisition
  - Specifications
- Road Profiling
  - Road Theory and IRI
  - Operation using Keypad and Display
- How to Collect Data
- Data Analysis
- Maintenance
Profiler Firmware, Software and Hardware Configuration

- Installed **latest firmware upgrades** to 4000 model software without requiring hardware replacement. Supports constant distance sampling.
- Installed **latest software upgrades** to 4000 model
- Inspected and adjusted hardware to confirm correct configuration and performance
  - Performed **acceleration compensation test**
Operator Hands on Training in the Field

- Powering on and configuring reference profiler by setting parameters using menu
- Starting (accelerating) and stopping (decelerating) the profiler
- Keeping steady speed
- Keeping vertical orientation
- Using pointer to precisely follow profile line.
- Running closed loop profiles
Profiler Calibration and Testing

- Prepare Calibration Site
  - Measured precise 200 foot long profile using accurate 300 foot steel tape
  - Marked high visibility chalk line

- Perform Distance (DMI) Calibration
  - Set 200 foot distance calibration parameter in menu
  - Run full length in distance calibration mode
Profiler Calibration and Testing

- Cross Axis Calibration
  - 3 forward runs with intentional tilting at 3 different tilts: left 5°, right 5° and 0° (vertical or no tilt)
  - Use Cross Axis Autocalibration to calculate ideal cross axis calibration

- Closed Loop Profiles
  - Confirm performance
What is Cross Axis Error?

- Small misalignment of sensing element of inclinometer accelerometer with longitudinal axis of its own case and/or of the case with the longitudinal axis of profiler. A rotation around z axis.

- Rotation of inclinometer by angle $e$ results in sensitivity in cross axis (x direction) of $I_x$. This is Cross Axis Error which is a profile signal error.
Profiler Calibration and Testing

Cross Axis Calibration

Tilting Profiler Changes End Elevation because of Cross Axis Error
Profiler Calibration and Testing

Cross Axis Calibration

Cross Axis Autocal function performs regression analysis to determine sensitivity to cross axis tilting of:

\[ \text{fi}_\text{sensitivity}_\text{to}_x = 1.814354 \times 10^{-1} \text{ V/G} \]

With \( R^2 \) of 0.99961 indicating excellent straight line fit.

![Graph showing change in end elevation (mm) vs. tilt (volts) with three runs: Left Tilt Run, No Tilt Run, and Right Tilt Run.](image)

- Left Tilt Run
- No Tilt Run
- Right Tilt Run
Profiler Calibration and Testing

Closed Loop Runs

Mean IRI Repeatability Cross Correlation = 98.5%
Training Area Results

- All participants >98.4% IRI Cross Correlation
- Generally good IRI Roughness agreement
Setting Up Certification Site

- Measure total 681 feet profile with metal tape including:
  - 150 foot lead-in
  - 528 foot test section
  - 3 foot lead-out
- Snap full length chalk line and transverse start and end line

Typical LWP & RWP
Setting Up Certification Site

Snapping a chalk line through center of dots
Profile Test Sections

Section 1. New Ground JRCP section

Section 2. New Grooved CRCP section

Section 3. SMA & OGFC sections K&L

Start Data Collection 150 ft. before section 1
Profile Test Sections (cont.)

Section 4. SM 9.5

Section 5. SM 9.5/12.5
Section 1 Ground J RCP
IRI Comparison – Section 2 CRCP
Section 2 CRCP Ground & Grooved
Collecting Profile Data

- Both LWP and RWP at each Test Section for S1-S5
- Each Wheel Path
  - One DMI Calibration (save Dist Cal value)
  - One Closed Loop Run (both Forward and Reverse Run and save Elev Cal Value)
  - Two Additional Forward Runs for Total of 3
Collecting Profile Data
S1-5 Unfiltered Profile Data

MSDOT LWP and RWP

% GRADE
- S2, 5.98%
- S1, 5.96%
- S3, 5.40%
- S4, 4.54%
- S5, 2.90%

- S2, CRCP Grooved
- S1, JRCP Ground
- S3, SMA-OGFC
- S4, SM 9.5
- S5, SM 9.5/12.5
Effect of Grade on Profiling

Grade = 6%

\[ \alpha = 3.43^\circ \]

\[ \alpha = \tan^{-1} \left( \frac{6}{100} \right) \]

\[ F_s = 42 \sin \alpha \]

\( F_s = \) Force down slope = 2.5 lb force

Weight = 42 lb force
S1-5 Filtered Profile Data

MSDOT LWP and RWP after BW HP at 100 ft.

BW High Pass Filter Transient

S2
Collecting Profile Data

- Chigger-size profile on S2 RWP

Beware Of Chiggers!
S2, Smart Road’s Smoothest Pavement, IRI=40 in/mile

- MSDOT LWP and RWP after BW HP at 100 ft.

Profile height \(~=0.06\)” (1.5mm) or 3 chiggers high.
To measure to 1% resolution for Cross Correlation
requires 0.0006” or 0.015mm or 15um which
SurPRO 4000 supports.
Analysis of Profile Data

IRI RWP

Section

IRI LWP

Section

<table>
<thead>
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<th>Section</th>
<th>GDOT_before_coaching</th>
<th>GDOT_after_coaching</th>
<th>MSDOT</th>
<th>PENNDOT</th>
<th>VTTI</th>
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Coaching Operators

- Affect of handle position on S2

Power Spectral Density

0.8-0.9 ft/cycle
Analysis of Profile Data

IRI Cross Correlation RWP

IRI Cross Correlation LWP
S1 Mean IRI CC for 4 States

Using ProVAL Profiler Certification Module

RWP Mean CC of 4 States 99.24%

LWP Mean CC of 4 States 97.02%
S2 Mean IRI CC for 4 States

Using ProVAL Profiler Certification Module

RWP Mean CC of 4 States 89.9%

LWP Mean CC of 4 States 92.9%
S3 Mean IRI CC for 4 States

Using ProVAL Profiler Certification Module

RWP Mean CC of 4 States 97.7%

LWP Mean CC of 4 States 97.3%
S4 Mean IRI CC for 4 States

Using ProVAL Profiler Certification Module

RWP Mean CC of 4 States 97.3%

LWP Mean CC of 4 States 97.5%
S5 Mean IRI CC for 4 States

Using ProVAL Profiler Certification Module

RWP Mean CC of 4 States 96.1%

LWP Mean CC of 3 States 95.3%
After the Rodeo, by 2 operators alternating runs

<table>
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<th>Section</th>
<th>Pavement Type</th>
<th>LWP</th>
<th>RWP</th>
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<tr>
<td>1</td>
<td>JRCP</td>
<td>99.0</td>
<td>98.9</td>
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<tr>
<td>2</td>
<td>CRCP, grooved</td>
<td>97.4</td>
<td>97.2</td>
</tr>
<tr>
<td>3</td>
<td>SMA-OGFC</td>
<td>98.5</td>
<td>98.4</td>
</tr>
<tr>
<td>4</td>
<td>SM 9.5</td>
<td>99.3</td>
<td>99.0</td>
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<tr>
<td>5</td>
<td>SM 9.5/12.5</td>
<td>97.8</td>
<td>98.3</td>
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Things That May Adversely Affect Cross Correlations

- DMI Error
- Tire Emulation
  - Effects of Pavement Texture—Tire Bridging Filter
  - Tire Footprint Width
- Vertical Measurement Resolution and Accuracy
- Data Filtering Issues
- FAILURE TO FOLLOW SAME PROFILE LINE! Error of 1 in. or more will adversely affect Cross Correlations
Cross Correlating with Inertial Profilers—Marking Wheel Path

- Mark a profile line that an Inertial Profiler can follow accurately at 50 MPH.
  - First temporarily mark offset from road edge to wheel path line at regular intervals—say 30 feet
  - Use ¼ " rope pulled tight or laser to define a "Best Fit“ of straight line through temporary marks—this will be line that can be followed by Inertial Profiler
  - Spray paint rope or snap chalk line on straight line
  - For driver visibility mark dots centered on line
Cross Correlating with Inertial Profilers—Steering

- Driver has Parallax Error viewing wheel path line—difficult to judge if on line
- Driver needs a Heads Up Display showing Low Angle View of wheel path
- If not already equipped mount a Low Angle video camera above wheel path laser
- Record camera video for later correlation with profiles
Observations & Conclusions

- Training of Operators was Successful
  - Learned new skill or improved skills for Reference Profiler configuration, calibration and operation
- Set up Certification Sites
- Good Agreement of 4 State DOTs Profiling Sections S1 to S5
  - Achieved mean IRI Cross Correlation of 4 Different SurPROs typically 97%
Observations & Conclusions

- Smart Road’s Characteristics Presented
  Challenges for Profiling

  - Grade requires Reference Profiler operator to oppose component of Reference Profiler weight parallel to slope

- Smooth Pavement IRI Repeatability Cross Correlation

  - 97.2% on S2 RWP with IRI of 40 in/mile

- VTTI achieved 98-99% after the Rodeo
Thanks!

- VTTI and Staff
- GADOT
- MSDOT
- PENNDOT
More Information

- www.surpro.com
- www.internationalcybernetics.com