Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Workshop Agenda
(4-Hour Workshop Format)

WORKSHOP OBJECTIVES

- To educate pavement practitioners on the fundamentals of concrete pavement smoothness measurement and interpretation.
- To reinforce best practices for concrete paving operations to achieve ride quality requirements.
- To demonstrate Real-Time Smoothness technology as a tool for improving concrete pavement smoothness.

WORKSHOP SCHEDULE

0:15	Session 1: Welcome and Overview
0:30	Session 2: Fundamentals & Importance of Pavement Smoothness
0:45	Session 3: RTS Measurement Technology and Practices
0:30	Session 4: Fundamentals of Ride Quality and Current Practices for IRI Specs
0:45	Session 5: Best Practices for Concrete Paving Operations
1:00	Session 6: Using RTS Technology to Improve PCCP Smoothness
0:15	Q&A

WORKSHOP INSTRUCTORS

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FOR MORE INFORMATION

http://www.fhwa.dot.gov/goshrp2/Solutions/Renewal/R06E/Tools_to_Improve_PCC_Pavement_Smoothness_During_Construction

SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Session 1: Welcome and Overview

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Session 1: Welcome and Overview

- Introductions
- Workshop Overview and Objectives
- Introduction to Real-time Smoothness (RTS) Technology

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Introductions

- Name
- Agency and location
- Interest in concrete paving and smoothness measurements
- Experience with RTS technology

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Instructors

Gary Fick

Trinity Construction Management Services, Inc.

(Edmond, OK)

David Merritt

The Transtec Group, Inc.

(Austin, TX)

National Concrete Pavement Technology Center

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Who Sponsors this Effort?

- SHRP2 Solutions is a collaborative effort of AASHTO, FHWA and TRB
- Funding research projects for:
  - Making highways safer
  - Fixing deteriorating infrastructure
  - Reducing congestion

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SHRP2-R06(E)

- 2009 – 2011 SHRP2 effort to demonstrate and evaluate existing RTS measuring technologies.
  - Georgia, Arkansas, Texas, Michigan & New York
- Developed draft model specifications and guidelines.
- Final report online:

http://www.trb.org/Main/Blurbs/167282.aspx

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Implementation Support

National Concrete Pavement Technology Center

Current effort involves:

- Equipment Loan Program
- Showcases
- Workshops
- Documentation of results/case studies
- Specification Refinement

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Workshop Goals

- To educate pavement practitioners on the fundamentals of concrete pavement smoothness measurement and interpretation.
- To reinforce best practices for concrete paving operations to achieve ride quality requirements.
- To demonstrate Real-Time Smoothness technology as a tool for improving concrete pavement smoothness.

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Workshop Topics

- Measuring Pavement Profiles
- Introduction to Real-Time Smoothness Technology
- Interpreting and Analyzing Pavement Profiles
  - What is the IRI and what are current specification requirements?
  - What is localized roughness?
  - ProVAL software analysis tools
- Best Practices for Concrete Paving Operations
- Using RTS Technology to Improve Smoothness

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Workshop Outline

- Session 2: Fundamentals & Importance of Pavement Smoothness
- Session 3: RTS Measurement Technology and Practices
- Session 4: Fundamentals of Ride Quality and Current Practices for IRI Specs
- Session 5: Best Practices for Concrete Paving Operations
- Session 6: Using RTS Technology to Improve PCCP Smoothness

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What is RTS Measurement?

Real-time smoothness refers to measuring and evaluating the concrete pavement surface profile during construction, somewhere along the paving train while the concrete surface is still wet (plastic).

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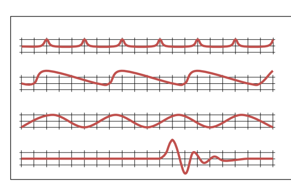
With RTS Measurements You Can…

- Identify events during concrete paving that affect smoothness.
- Examples:
  - Dowel basket rebound
  - Concrete load effects
  - Stringline sag
  - Localized roughness
  - Etc.



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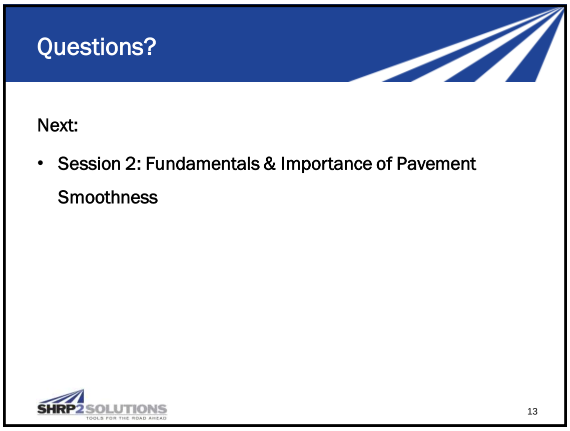
Questions?
Next:
• Session 2: Fundamentals & Importance of Pavement Smoothness
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TOOLS FOR THE ROAD AHEAD

Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Session 2: Fundamentals and Importance of Pavement Smoothness

U.S. Department of Transportation Federal Highway Administration

AASHTO

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

Session 2: Fundamentals and Importance of Pavement Smoothness

- Importance of Pavement Smoothness
- Fundamentals of Pavement Smoothness Measurement
  - What is a pavement profile?
  - How do we measure pavement profiles?

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Importance of Pavement Smoothness

Key reasons why smoothness is important (Agency Perspective):

1. It's important to the user (taxpayer).
2. Smoother roads last longer.
3. Smoother roads stay smoother longer.
4. Smoother roads are safer.
5. Smoother roads save money.

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Importance of Pavement Smoothness

Key reasons why smoothness is important (Contractor Perspective):

1. Reflects the quality of your work.
2. $$$

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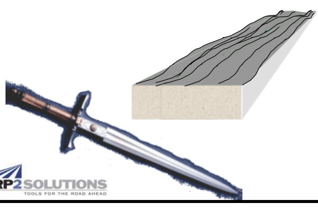
How do we measure smoothness?

A *profile* is a slice of the road surface following an imaginary line



Source: FHWA ProVAL Workshop

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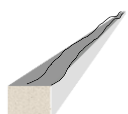
How do we measure smoothness?

A *profile* is a slice of the road surface following an imaginary line



Source: FHWA ProVAL Workshop

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How do we measure smoothness?

A *profile* is a slice of the road surface following an imaginary line

Source: FHWA ProVAL Workshop

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Measuring Profiles: Rolling Straightedge

Source: FHWA ProVAL Workshop

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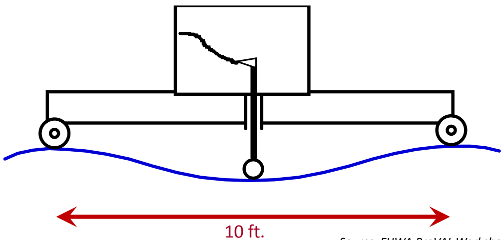
Measuring Profiles: Rolling Straightedge

Rolling Straightedge Response



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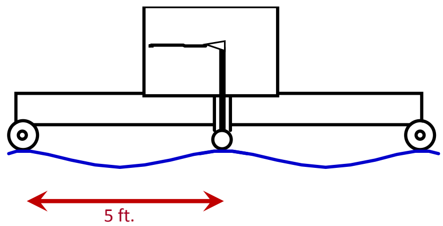
Measuring Profiles: Rolling Straightedge

Rolling Straightedge Response



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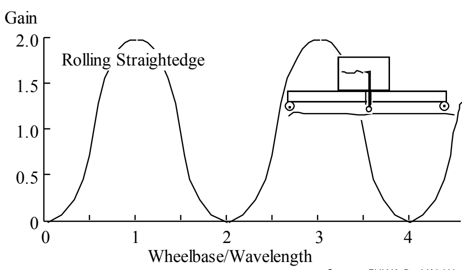
Measuring Profiles: Rolling Straightedge

Frequency Response



Source: FHWA ProVAL Workshop

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Measuring Profiles: Profilograph

Source: FHWA ProVAL Workshop

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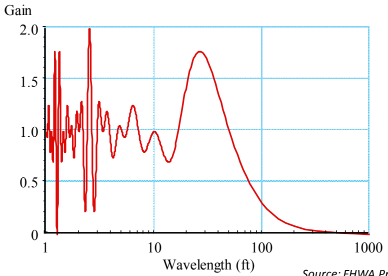
Measuring Profiles: Profilograph

Frequency Response



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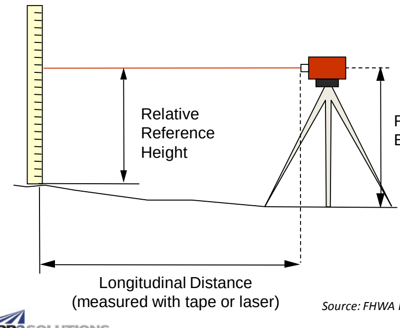
Measuring Profiles: Rod & Level



Source: FHWA ProVAL Workshop

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Measuring Profiles: Rod & Level

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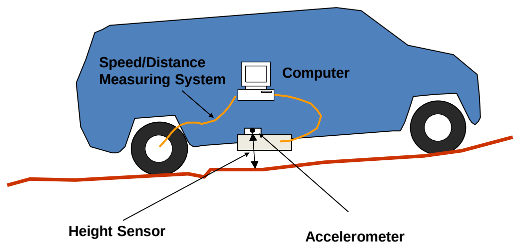
Measuring Profiles: Inertial Profiler



Source: FHWA ProVAL Workshop

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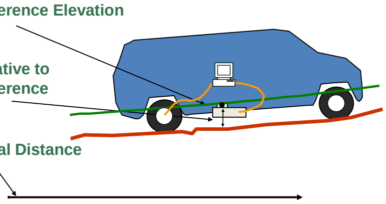
Measuring Profiles: Inertial Profiler

Works by combining three ingredients:

1. Inertial Reference Elevation
2. Height Relative to Inertial Reference
3. Longitudinal Distance



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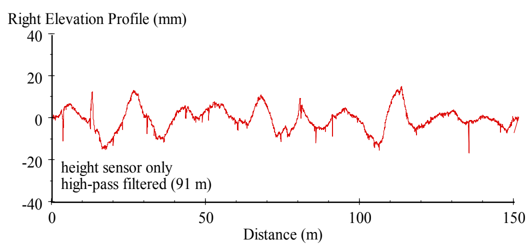
Profile Data

Height Sensor:



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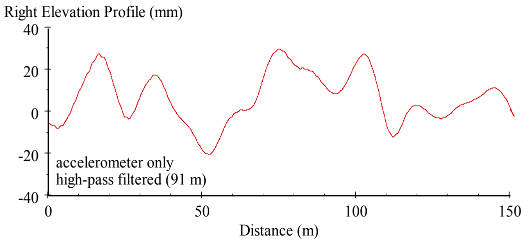
Profile Data

Accelerometer:



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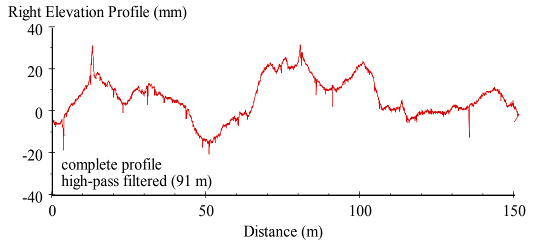
Profile Data

Complete Profile:



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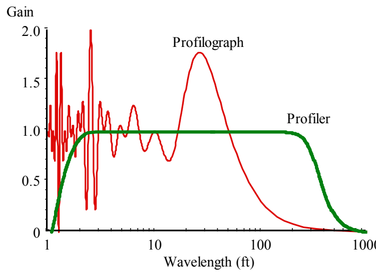
Profilograph versus Inertial Profiler



Source: FHWA ProVAL Workshop

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Inertial Profiler: High Speed

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Inertial Profiler: Lightweight

Source: FHWA ProVAL Workshop

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Other Profiler Types

Dipstick®

ARRB Walking Profiler

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Other Profiler Types

SSI Walking Profiler

SurPro Walking Profiler

Source: FHWA ProVAL Workshop

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Other Profiler Types

Real-Time Profiler (inclinometer based)

Ultrasonic Sensors

Laser Sensors

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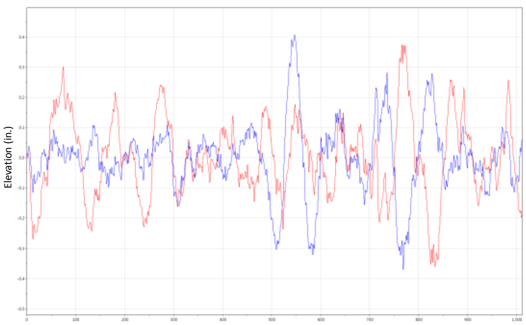
Real-Time Profiler Data



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Recap

- We want to measure the “actual profile” or actual shape of the pavement surface with our profiling device.
- High Speed/Lightweight Inertial Profilers or Walking Profilers give us the best representation of the actual profile.
- RTS profilers give us this same information while the concrete is still plastic.

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Questions?

Next:

- Session 3 - RTS Measurement Technology and Practices

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Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Session 3: RTS Measurement Technology and Practices

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Session 3: RTS Measurement Technology and Practices

- Benefits and limitations of RTS technology
- Overview of current RTS devices – Ames RTP & GOMACO GSI
- Options for mounting RTS devices (paver/work bridge/cure cart, wheelpath/center of lane, etc.)
- Examples of RTS output/profile trace
- Best practices/lessons learned

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What is RTS Measurement?

Recap: Real-time Smoothness refers to measuring and evaluating the concrete pavement surface profile during construction, somewhere along the paving train while the concrete surface is still wet (plastic).

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RTS Measurements: Benefits

- Innovative tools for evaluating concrete pavement smoothness in real time.
- Tools that can be used for quality control and process improvements.
- Process improvements as a result of timely feedback.
- Improved understanding about how construction artifacts can affect smoothness.

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RTS Measurements: Limitations

- Not a replacement for conventional profiling for acceptance.
- Not a replacement for better practices to construct smoother pavements.

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RTS Profilers

Paver-Mounted GOMACO Smoothness Indicator (GSI)

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RTS Profilers

Stand-Alone GOMACO GSI Machine

RTS Profilers

Ames Engineering Real Time Profiler (RTP)

RTS Mounting

Possible sensor configurations:

- Mounted to the back of the paver (main pan or finish pan).
- Mounted to a trailing work bridge or texture/cure cart.
- Dedicated machine (GSI) located behind the finishers or texture/cure cart.
- Combination of sensors, such as a paver mounted followed by sensors on a work bridge/stand-alone machine.

RTS Mounting

Lateral configurations:

- Mounted in the lane wheelpaths (corresponding to hardened profile acceptance).
- Mounted mid-lane.
- Mounted where profile is traditionally rougher (paver configuration dependent).

RTS Mounting

- GSI and Ames RTP mounted to the back of a paver in the wheelpaths:

RTS Mounting

- GSI machine, after finishers, before texture/cure cart:

RTS Mounting

- Ames RTP equipment mounted to a self-propelled work bridge:

RTS Mounting

- GOMACO GSI and Ames RTP mounted to a towed work bridge:

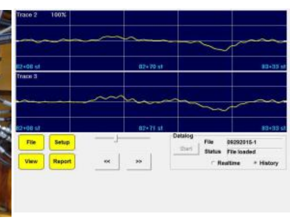
RTS Measurements

- Real-time feedback, viewing and analysis capabilities:

RTS Measurements

- Real-time feedback, viewing and analysis capabilities:

GSI



RTS Measurements

- Real-time feedback, viewing and analysis capabilities:

Ames RTP

Contractor Feedback/ Lessons Learned

- Contractor and agency can “see” things in real-time that used to take 24-48 hours
- RTS overall improves the paving process through better quality and improved efficiency
- Well suited for:
  - Identifying operational changes on smoothness
  - Tuning the paver
  - Quality control
  - Troubleshooting and correcting problems early

Contractor Feedback/ Lessons Learned

- Contractors using RTS equipment are observing ~20-50% difference between real-time (wet) and QC numbers (hardened)
- 100 in/mi real-time is typically equivalent to 75 in/mi hardened
  - The higher the real-time numbers the greater the percent difference.
  - The lower the real-time numbers the tighter the correlation with QC numbers.

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Contractor Feedback/ Lessons Learned

- Why is the real-time profile rougher than the hardened?
  - Fixed height of real-time sensor (no accelerometer)
  - Vibrations from the paver (measurement error) are interpreted as profile deviation
  - Hand finishing removes localized roughness, especially true for higher real-time readings

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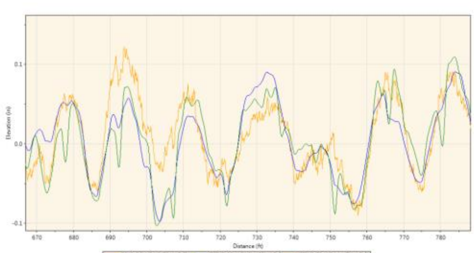
Contractor Feedback/ Lessons Learned

- Good, but not perfect, between RTS and hardened profiles



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Contractor Feedback/ Lessons Learned

- Does it matter that real-time data is rougher than hardened profile data?
  - Concentrate on lowering the real-time numbers
  - This will translate to lower hardened numbers (smoother pavement)

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Contractor Feedback/ Lessons Learned

- Equipment adjustments that can be reflected in RTS measurements:
  - Paver speed
  - Vibrator frequency
  - Vibrator height
  - Sensitivity of paver elevation controls (hydraulics and stringless)
  - Oscillating correcting beam frequency
  - Draft (angle of attack)
  - Others

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Contractor Feedback/ Lessons Learned

- Process adjustments that can be reflected in RTS measurements:
  - Concrete workability
  - Concrete delivery/spreading procedures
  - Stringline tension
  - Hand finishing techniques (when sensors are mounted to a trailing work bridge)
  - Concrete uniformity
  - Stopping the paver vs. slowing the paver
  - Concrete head (height and uniformity)
  - Others

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Contractor Feedback/ Lessons Learned

- It takes changing the current mindset:
  - Finishing crews used to actively finishing to meet smoothness specifications
- Now RTS equipment allows crews to:
  - Monitor smoothness
  - Locate and verify bumps/deficiencies,
  - Check with a straightedge
  - Try to correct it

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Contractor Feedback/ Lessons Learned

- Paving Crew Training
  - Current mindset: extra person needed to monitor RTS device
  - Not necessarily correct - lead finisher tends to understand the device and assumes the role to monitor it
- Download the RTS files at the end of each day for analysis.
  - ProVAL comparisons of real-time (wet) vs. QC (hardened) measurements

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Contractor Feedback/ Lessons Learned

- Tool for paving foreman, paver operator.
  - Monitor for equipment mechanical problems
  - Effect of events on smoothness: paver stops, paver adjustments, etc.
- Tool for finishing crews to monitor smoothness.
  - Typically monitor 100-ft average IRI
- Preferred mounting location is to the back of the paver.

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Questions?

Next:

Session 4 – Fundamentals of Ride Quality and Current Practices for IRI Specs.

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TOOLS FOR THE ROAD AHEAD

Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Session 4: Fundamentals of Ride Quality and Current Practices for IRI Specs

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TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

Session 4: Fundamentals of Ride Quality and Current Practices for IRI Specs

- Where did IRI come from?
- Common IRI surrogates found in specifications: MRI and HRI
- ProVAL software for analyzing profile data.
- Current practices for concrete pavement smoothness specifications nationally.

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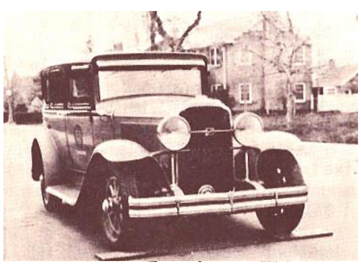
Response-Type Systems



Source: FHWA ProVAL Workshop

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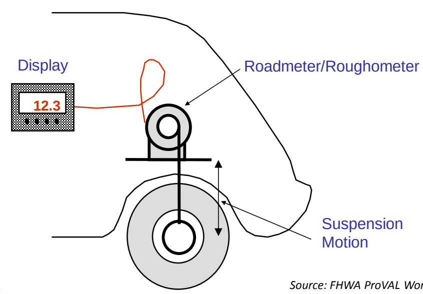
Response-Type Systems



Source: FHWA ProVAL Workshop

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Response-Type Systems

Response-Type Trailer

Source: FHWA ProVAL Workshop

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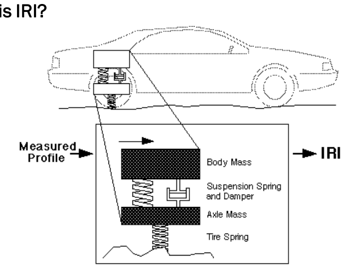
International Roughness Index (IRI)

What is IRI?



Quarter-Car Model

Source: FHWA ProVAL Workshop

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International Roughness Index (IRI)

Quarter-Car Simulation

Source: FHWA ProVAL Workshop

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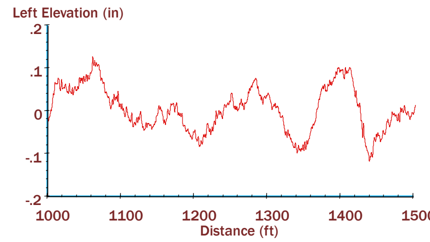
Pavement Profile Data



Source: FHWA ProVAL Workshop

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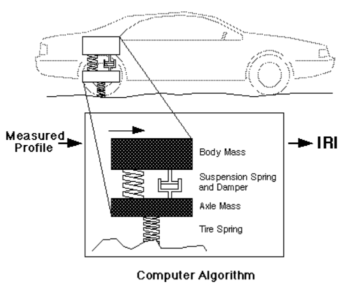
IRI Computation



Source: FHWA ProVAL Workshop

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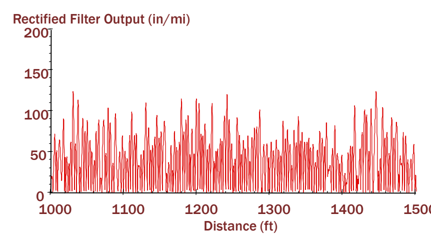
IRI Response



Source: FHWA ProVAL Workshop

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IRI Reporting Options

- Overall Roughness
  - Single value for the IRI of the profile trace
- Fixed Interval Report
  - IRI reported on a lot-by-lot basis
- Continuous Roughness Report
  - IRI reported based on a moving average “baselength”

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Half-Car Roughness Index (HRI)

- Calculated from two profiles
- The profiles are averaged point-by-point to create an “average” profile
- The IRI algorithm is applied to the resulting profile

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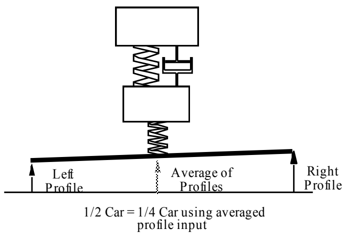
Half-Car Roughness Index (HRI)



Source: FHWA ProVAL Workshop

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Mean Roughness Index (MRI)

- Calculated from two profiles (generally from the two wheelpaths).
- The IRI algorithm is applied to each profile separately.
- Computed IRI values are averaged and reported as MRI.

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Localized Roughness

- Isolated areas that contribute disproportionately to overall roughness.
- “Hot Spots” or “Must Grinds”
- Identified using:
  - Short baselength continuous roughness (IRI) reports
  - Short segment fixed interval IRI
  - Profile moving average
  - Profilograph Simulation
  - Straightedge

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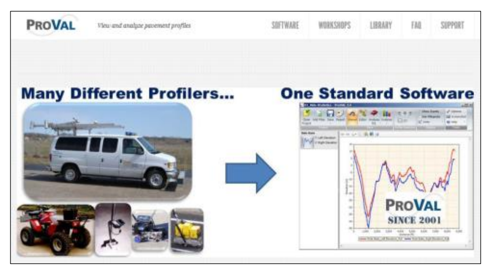
Evaluation of Profiles: ProVAL Software



www.RoadProfile.com

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What is ProVAL?

- Software application to <u>view</u> and <u>analyze</u> pavement profiles in many different ways.
- Easy to use and yet powerful to perform many kinds of profile analyses.

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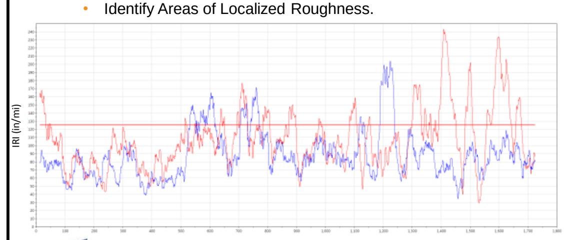
Key ProVAL Modules

- Roughness Report
  - Compute and summarize IRI for profiles.
  - Identify Areas of Localized Roughness.



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Key ProVAL Modules

- Profile Synchronization
  - Line up repeat profile runs.
- Smoothness Assurance Module (SAM)
  - Diamond grinding simulation
  - Side-by-side comparison of profile and roughness

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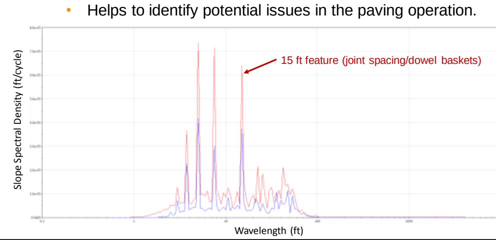
Key ProVAL Modules

- Power Spectral Density (PSD)
  - Identify dominating (repeating) features to contribute roughness.
  - Helps to identify potential issues in the paving operation.



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Power Spectral Density (PSD)

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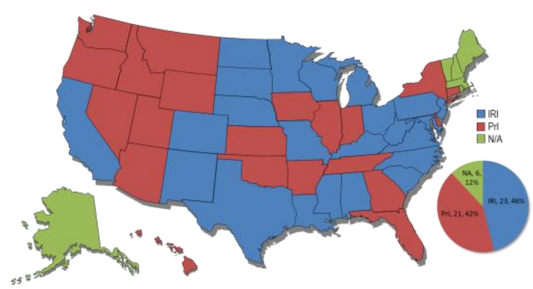
PCC Pavement Smoothness Specifications



Merritt et al. 2015

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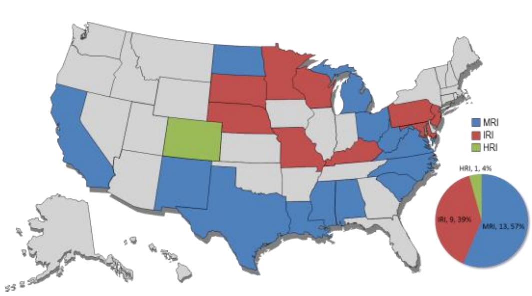
22

PCC Pavement Smoothness Specifications



Merritt et al. 2015

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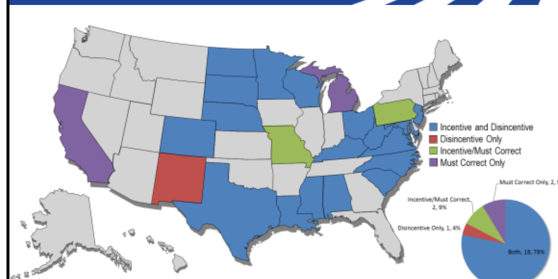
PCC Pavement Smoothness Specifications



Merritt et al. 2015

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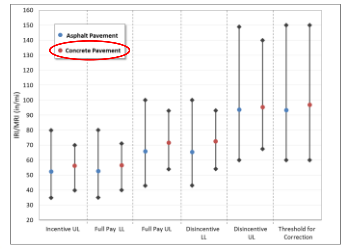
PCC Pavement Smoothness Specifications

- Summary of IRI-based specification thresholds for PCC pavements:

		Incentive Upper Limit	Full Pay Lower Limit	Full Pay Upper Limit	Disincentive Lower Limit	Disincentive Upper Limit	Threshold for Correction
MRI & IRI (22 states)	*min*	39.9	40.0	54.0	54.1	67.5	60.0
	max	70.0	71.0	93.0	93.1	140.0	150.0
	avg.	56.2	56.5	71.7	72.5	95.3	96.9
HRI (CO only)		57.9	58.0	67.0	67.1	85.0	85.0

PCC Pavement Smoothness Specifications

- Comparison of specification thresholds for asphalt and concrete pavement for IRI/MRI:



PCC Pavement Smoothness Specifications

- Range of Incentive/Disincentives applied for ride quality:

Pay Adjustment Basis		Maximum Incentive	Maximum Disincentive
$ per lot (0.1 mi) *9 states*	*min*	$200	-$250
	max	$1,600	-$1,750
	avg.	$879	-$900
$ per lot (SY) *2 states*	*min*	$1.40	-$1.12
	max	$1.40	-$1.40
	avg.	$1.40	-$1.26
$ per lot (1.0 mi) *1 state*		$7,350	-$7,350
$ per lot (0.01 mi) *1 state*		$50	-$500
$ per lot (500 ft.) *1 state*		$250	-$250
Extended Pay Adjustment $ per lot (0.1 mi) *13 states (NJ excluded)*	*min*	$200	-$250
	max	$1,600	-$1,750
	avg.	$825	-$831
Percent Contract Price *7 states*	*min*	102%	90%
	max	108%	50%
	avg.	105%	75%

PCC Pavement Smoothness Specifications

- Summary of localized roughness provisions for IRI-based specifications:

Method	Number of States		Range	
	Asphalt	*Concrete*		
Continuous IRI (25 ft. baselength)	11	12	80 in/mi	200 in/mi
Fixed Interval IRI	4	4	25 ft. segment: 150-160 in/mi	0.01 mi (52.8 ft.) segment: 100-125 in/mi
Profile Moving Average (25 ft. baselength)	4	1	0.15 inches	0.4 inches
Profilograph Simulation (25 ft. baselength)	2	2	0.3 inches	0.4 inches
Straightedge Only	18	4	1/8-inch in 16 ft.	1/4-inch in 10 ft.

PCC Pavement Smoothness Specifications

- Range of Disincentives applied for localized roughness:

	Concrete Pavement *(3 states)*
Min	-$10
Max	-$250
Average	-$173

Recap

- ✓ We discussed what the IRI is and where it came from.
- ✓ We discussed ProVAL as a tool for analyzing profile data (from RTS or hardened profiles).
- ✓ We discussed current practices for IRI specifications for concrete paving.

Questions?

Next:

Session 5 – Best Practices for Concrete Paving Operations

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Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Session 5: Best Practices for Concrete Paving Operations

U.S. Department of Transportation Federal Highway Administration | AASHTO | TRANSPORTATION RESEARCH BOARD

Session 5: Best Practices for Concrete Paving Operations

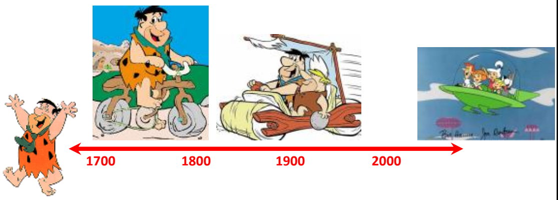
- Key aspects of concrete paving that affect smoothness.
- Importance and potential cost-savings of identifying smoothness issues during construction (real-time).

SHRP2 SOLUTIONS 2

In the Beginning ...

- A brief history of surface transportation:

  Walking, horse, camel or llama before 1790



SHRP2 SOLUTIONS 3

1924

SHRP2 SOLUTIONS 4

Circa 1950

SHRP2 SOLUTIONS 5

1968

SHRP2 SOLUTIONS 6

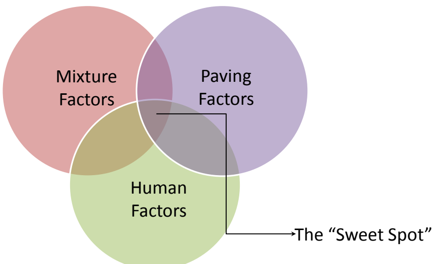
2015

Ten Commandments of Concrete Pavement Smoothness (1988)

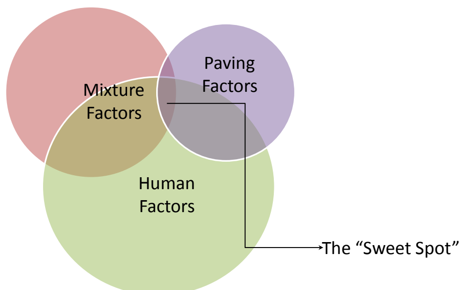
1. Develop a smoothness plan for the project.
2. Develop an accurate field survey for stringline/stringless controls.
3. Properly prepare the grade, providing a stable form or track line.
4. Set up proper forms properly for fixed-formed paving.
5. Use a consistent concrete mixture appropriate for the paving method.
6. Deliver and place concrete consistently.
7. Set-up and operate the paver steadily.
8. Fasten dowels/reinforcing securely and use "bump-free" construction joints (headers).
9. Use only necessary and appropriate finishing techniques.
10. Apply texturing and curing with care.

Source: Chapin Cipherd, CMI Corp.

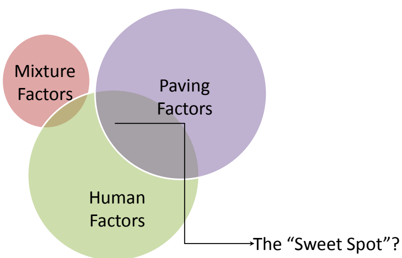
21st Century Approach



21st Century Approach



21st Century Approach



Mixture Factors

- Combined gradation
- Between batch uniformity
- Uniform delivery of concrete

Combined Gradation

Remember the purpose of an optimized gradation:

- Economically combining aggregate particles to achieve the desired objectives of:
  - Reduced paste content
  - Improved workability
  - Durability
- **An optimized mixture must be workable in the field to achieve durability**
- **The Tarantula Curve was developed concurrently with a lab test that evaluates a concrete mixture's response to vibration**

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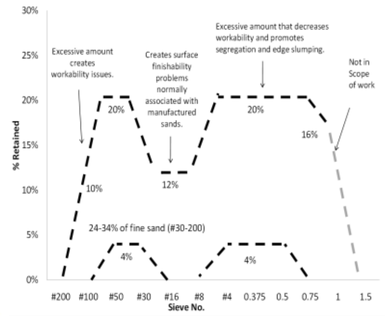
Combined Gradation: The Tarantula curve



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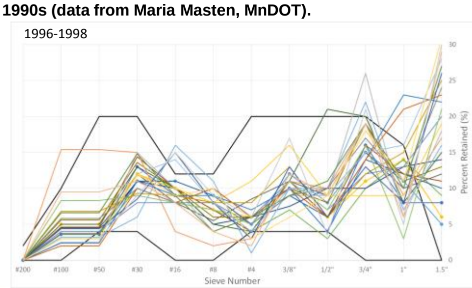
Combined Gradation: Tarantula Curve Validation

Minnesota DOT implements a combined gradation specification in the late 1990s (data from Maria Masten, MnDOT).



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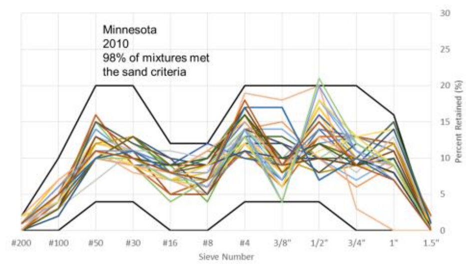
Combined Gradation: Tarantula Curve Validation

With added experience, the field mixtures continue to be refined and further reflect the Tarantula Curve recommendations .



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Combined Gradation: Best Practices

- The distribution of fine sand can vary largely without affecting the workability.
- An aggregate volume between 24% to 34% is recommended for #30 - #200.
  - This range was similar for multiple gradations and aggregate sources.
- More than 20% retained on the #30 sieve size created finishing issues.

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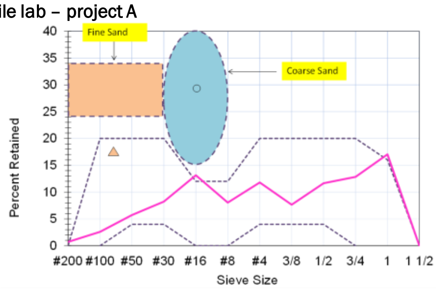
Combined Gradation Tarantula Curve Example

FHWA mobile lab – project A



SHRP2 SOLUTIONS Images from Jagan Gudimettla 18

Combined Gradation Tarantula Curve Example

FHWA mobile lab – project A

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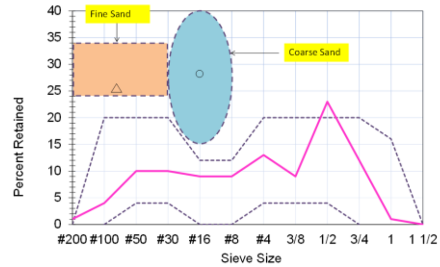
Images from Jagan Gudimettla 19

Combined Gradation Tarantula Curve Example

FHWA mobile lab – project B



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Images from Jagan Gudimettla 20

Combined Gradation Tarantula Curve Example

FHWA mobile lab – project B

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Images from Jagan Gudimettla 21

Between Batch Uniformity

Consistent combined gradation and water content

- **Scales in tolerance**
- **Uniform stockpile moistures**
- **Eliminate stockpile segregation**

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Uniform Delivery of Concrete

Translates to minimizing paver stops

- **Plant production capacity must be able to feed the paver**

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Paving Factors

- Track line
- Stringline/Stringless model
- Paver setup
  - Draft/Lead
  - Sensitivities
  - Vibrator frequency
  - Vibrator height
  - Float pan
- Concrete head
- Curing and texturing

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Track Line

Minimize extreme leg barrel movements:

- Profile – trimmed or stabilized base placed with grade control
- Stability – non-yielding and non-pumping
- Width – full width of track supported

SHRP2 SOLUTIONS — TOOLS FOR THE ROAD AHEAD 25

Track Line

SHRP2 SOLUTIONS — TOOLS FOR THE ROAD AHEAD 26

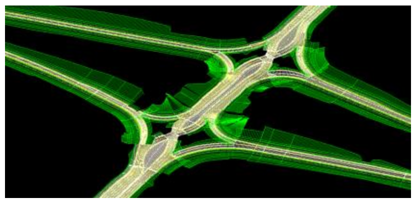
Stringline

- Adjusted for smoothness
- Properly and uniformly tensioned
- Pin spacing

SHRP2 SOLUTIONS — TOOLS FOR THE ROAD AHEAD 27

Stringless Model

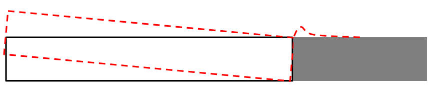
- Smooth transitions
- Point spacing or true curves
- Control points



SHRP2 SOLUTIONS — TOOLS FOR THE ROAD AHEAD 28

Paver Setup

- Draft/Lead – paver should be as flat as you can get it



SHRP2 SOLUTIONS — TOOLS FOR THE ROAD AHEAD 29

Paver Setup

- Sensitivities
  - Sensors
  - Stringless

SHRP2 SOLUTIONS — TOOLS FOR THE ROAD AHEAD 30

Paver Setup

- Vibrator frequency
  - Adjust for paving speed
  - Adjust for mixture
  - Slower at edges

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Paver Setup

- Vibrator height – adjust for base stiffness and optimize for smoothness

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Concrete Head

- Starts with subbase uniformity (grade control)
- Maintain a uniform head pressure

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Concrete Head

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Curing and Texturing

- Cure before any surface evaporation occurs to reduce warping.
- Texture
  - Minimize positive texture
  - Uniform texture depth

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Hand Finishing?

- Is it necessary?

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Hand Finishing?

- Does it improve the pavement smoothness?


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Human Factors

- Training
- Experience
- Communication
- Empowerment

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Human Factors

- Training
  - Everyone on the project contributes to smoothness
  - Each crew member should understand how their tasks impact smoothness – the "**BIG PICTURE**"

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Human Factors

- Experience
  - "The only source of knowledge is experience." (Einstein)
  - Crew retention and continuity is essential

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Human Factors

- Communication
  - "The single biggest problem in communication is the illusion that it has taken place." (George Bernard Shaw)
  - Establish clear lines of communication, so that everyone is on the same page
  - Radios, phones, hand signals, etc.
  - Listen to crew members

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Human Factors

- Empowerment
  - Encourage innovation
  - Enable decision making

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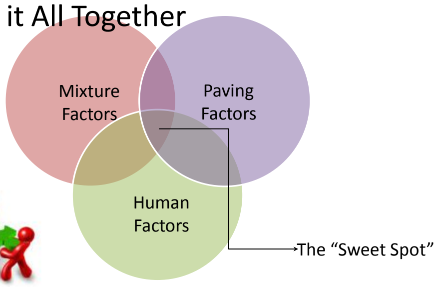
Summary of Best Practices

Putting it All Together



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Questions?

Next:

Sessions 6: Using RTS Technology to Improve Concrete Pavement Smoothness

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SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Session 6: Using RTS Technology to Improve Concrete Pavement Smoothness

U.S. Department of Transportation Federal Highway Administration

AASHTO

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

Session 6: Using RTS Technology to Improve Concrete Pavement Smoothness

- Introduction to using RTS Equipment.
- Experiences from RTS equipment loan program to date.

SHRP2 SOLUTIONS 2

Reasons for Using RTS Equipment

- Reduce disincentives
- Increase incentives
- Anticipated change in smoothness acceptance requirements
  - PrI to IRI
  - Change in localized roughness specification limits

SHRP2 SOLUTIONS 3

RTS Systems – Which One is Best?

- They both do the same thing - the correct question is, "which one is best for *me*?"
- Factors to consider:
  - Ease of mounting and switching between multiple pavers
  - Field ruggedness
  - Familiarity with Ames lightweight profiler systems
  - Laser vs. ultrasonic sensors

SHRP2 SOLUTIONS

RTS Mounting Locations

- Typically center of each driving lane
- Adjust this for special situations, when tuning the paver:
  - Tie bar insertion issues
  - One side of the paver is consistently rougher

SHRP2 SOLUTIONS 5

RTS Mounting Locations

SHRP2 SOLUTIONS 6

RTS Systems: Daily Setup and Shutdown

- Start-up - approximately 5 minutes
  - Install sensors and DMI
  - Connect cables
  - Input starting station and direction
  - Start the system
- Shut-down – approximately 5 minutes
  - Stop the system
  - Download data to a USB drive
  - Disconnect cables
  - Remove sensors and DMI

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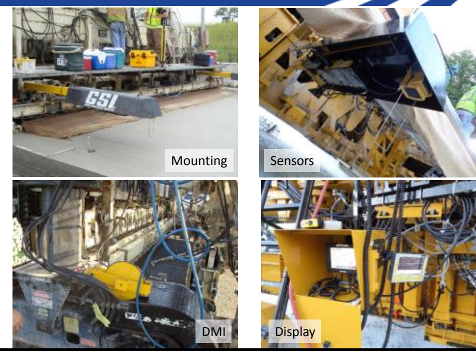
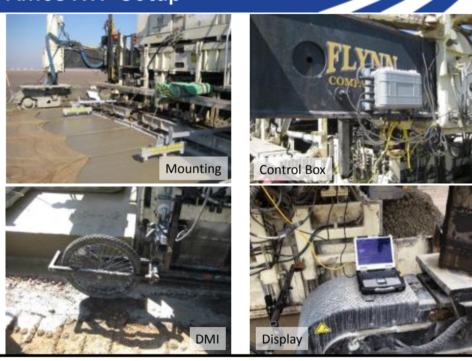
RTS Systems: GOMACO GSI Setup



8

RTS Systems: Ames RTP Setup



9

Using RTS Systems

- Step 1 – Establish a baseline
  - Monitor results for 1 to 2 days.
  - Keep processes static, but make ordinary adjustments.
  - Observe typical responses to the ordinary adjustments and make notes or add event markers in the RTS.
    - Mixture
    - Vibrators
    - Speed
    - Head
    - Paver stops
    - Etc.

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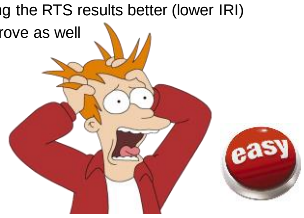
Using RTS Systems

- The RTS results are higher than the QC hardened profiles – what's up with that?
  - Don't panic
  - Just focus on making the RTS results better (lower IRI)
  - QC profiles will improve as well



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Using RTS Systems

- Step 2 – Pick the low hanging fruit
- Eliminate large events that cause excessive localized roughness.
  - Stringline/stringless interference
  - Paver stops
  - Padline issues
  - Etc.

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Localized Roughness Events

- Stringless system interference

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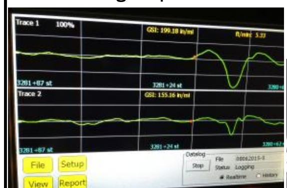
Localized Roughness Events

- Running the paver out of concrete



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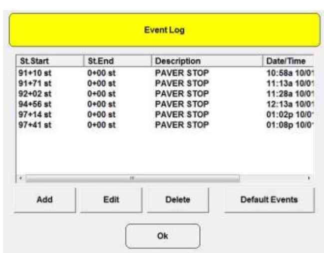
Localized Roughness Events

- Stopping the paver



Event Log

St.Start	St.End	Description	Date/Time
91+10 st	0+00 st	PAVER STOP	10:58a 10/01
91+71 st	0+00 st	PAVER STOP	11:13a 10/01
92+02 st	0+00 st	PAVER STOP	11:28a 10/01
94+56 st	0+00 st	PAVER STOP	12:13a 10/01
97+14 st	0+00 st	PAVER STOP	01:02p 10/0
97+41 st	0+00 st	PAVER STOP	01:08p 10/0

Add Edit Delete Default Events

Ok

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Using RTS Systems

- Step 3 – Adjust the paving process to improve overall smoothness
  - Maintain a consistent head
  - Lead/draft to get the paver as flat as possible
  - Sensitivities
  - Vibrators (height and frequency)
  - Mixture
  - Paver operation
  - Paving speed

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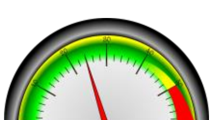
Overall Smoothness

- Eliminating big events gives you a new "baseline" to adjust from.
  - Systematically make changes in small increments.
  - Get a minimum of 0.1 mile with consistent paving (no big events) and then evaluate if the adjustment made things smoother.
  - Continue adjusting in small increments and evaluating every 0.1 mile.



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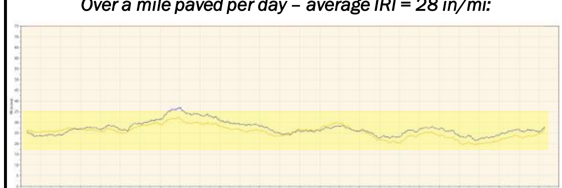
Overall Smoothness

- Stay focused and incredible things can happen

Over a mile paved per day – average IRI = 28 in/mi:



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Using RTS Systems

- Step 4 – Identify repeating features using a ProVAL PSD plot and adjust processes when possible.
  - Joints
  - Dumping/Spreading loads
  - CRCP bar supports

SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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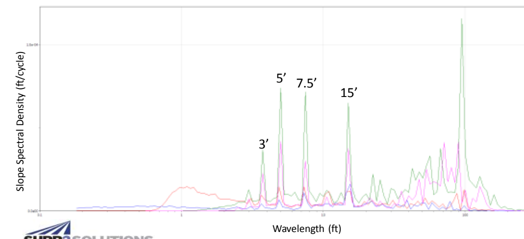
Repeating Features

- What repeating feature shows up here?
- What can you do to mitigate this feature?



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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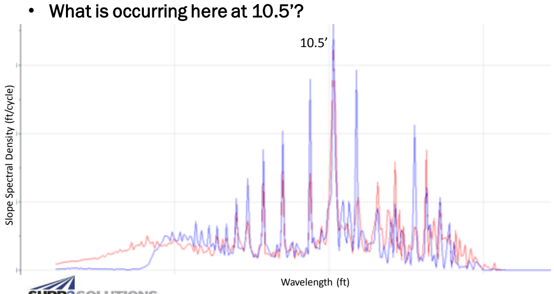
Repeating Features

- What is occurring here at 10.5'?



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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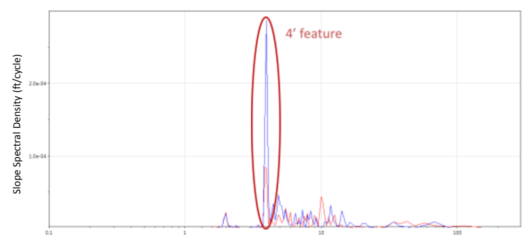
Repeating Features

- CRCP – what is contributing to roughness here?



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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SHRP2-FHWA RTS Equipment Loan

- Equipment Loans to Date
  - Idaho, I-84
  - Nebraska, I-80
  - Michigan, I-69
  - Texas, SH99
  - Pennsylvania, I-81
  - Iowa, Lyon Co. L-26
  - Illinois, I-90
  - Utah, I-215
  - Utah, I-15
  - California, SR-46

SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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Idaho, I-84

- Ames RTP
- Project Info
  - Widening of an existing interstate pavement
  - 12" JPCP over asphalt base (portion over agg. base)
  - 24' paving width, 15' joint spacing with dowel baskets
  - Stringless paving
  - Concrete deposited in front of paver with placer.

SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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Idaho, I-84

- Monitoring (4 days of paving)
  - Paver stops/starts
  - Concrete load consistency (wet/dry loads)
  - Concrete head in front of paver
  - Concrete level in grout box
  - Use of auto-float
- Hardened profile data collected the day following paving.

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Idaho, I-84

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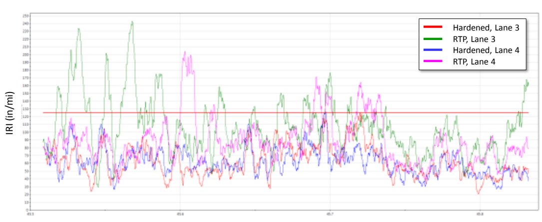
Idaho, I-84

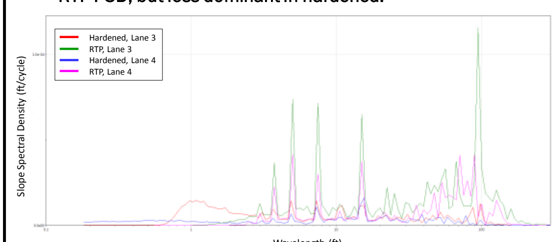
- RTP consistently measured higher roughness than hardened.



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD 27

Idaho, I-84

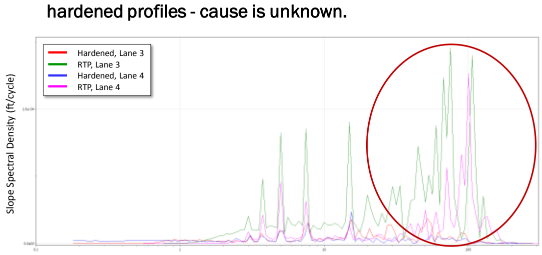
- Joint spacing was the dominant content in hardened and RTP PSD, but less dominant in hardened.



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD 28

Idaho, I-84

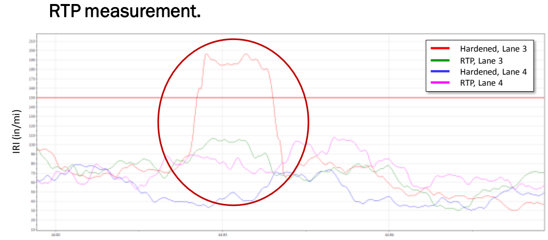
- Longer wavelength content (~40-100 ft) in RTP but not in hardened profiles - cause is unknown.



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD 29

Idaho, I-84

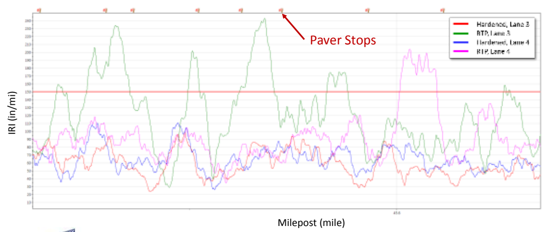
- Instance of roughness feature introduced into profile after RTP measurement.



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD 30

Idaho, I-84

- Paver stops appeared to have some effect on RTP measurements, but it was not consistent.



Idaho, I-84

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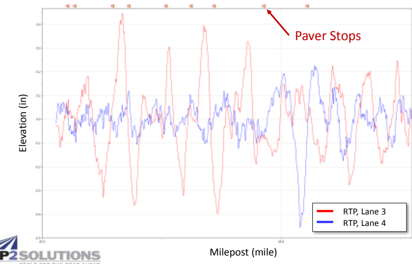


Idaho, I-84

- Changes to the concrete mixture after the first half of Day 1 were evident in the RTP smoothness data.
- There was no clear correlation between material head height (in the grout box) and profile or roughness.
- Although the auto-float was mounted behind the RTP, it did not appear to have an effect on hardened concrete profile or roughness.

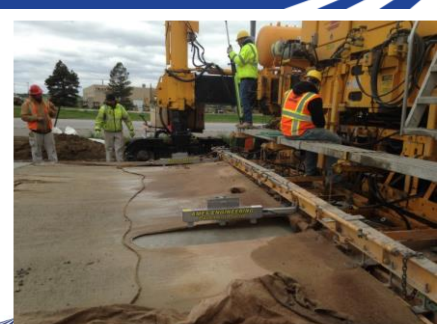
Nebraska, I-80

- Ames RTP
- Project Info
  - Mainline paving of interstate pavement
  - 13” JPCP over aggregate base
  - 24’ paving width, 16.5’ joint spacing with dowel baskets
  - Stringless paving
  - Concrete deposited in front of paver with placer.

Nebraska, I-80

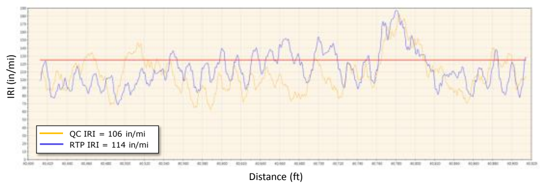
- Monitoring
  - Paver stops/starts
  - Concrete load consistency (wet/dry loads)
  - Concrete head
- Hardened profile data collected 1-2 days following paving.

Nebraska, I-80



Nebraska, I-80

- RTP showed only slightly higher IRI than hardened profiles.



SHRP2 SOLUTIONS

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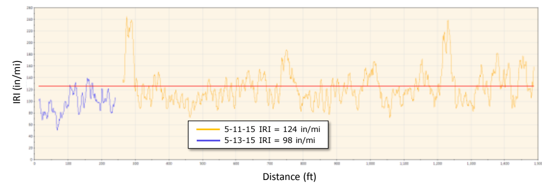
Nebraska, I-80

- Maintaining a consistent and smaller head of concrete in front of the paver significantly improved smoothness.



SHRP2 SOLUTIONS

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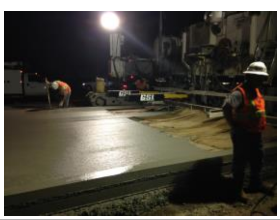
Texas, SH99

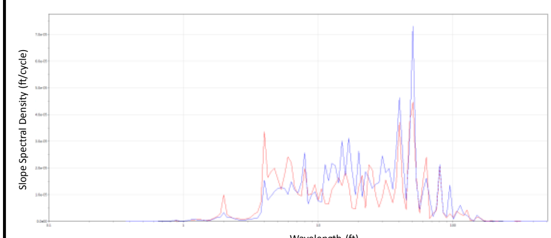
- GOMACO GSI
- Project Info
  - Paving of new mainline pavement
  - 12" CRCP over asphalt base



SHRP2 SOLUTIONS

Texas, SH99

- PSD content was sporadic on days with poor smoothness results.



40

Pennsylvania, I-81

- Real-time and hardened profiles parallel each other
- 20 in/mi difference

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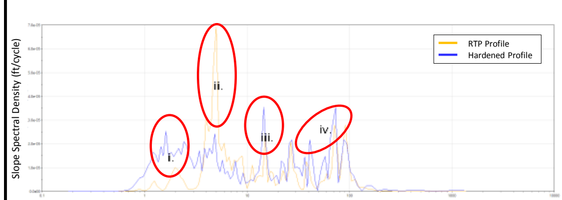
Pennsylvania, I-81

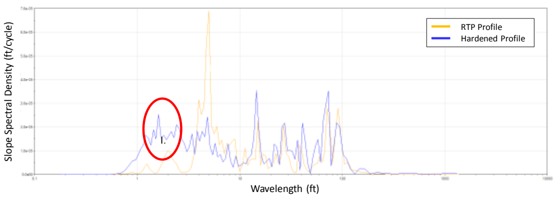
- Power Spectral Density for real-time and hardened profiles explains some of the 20 in/mi difference



42

Pennsylvania, I-81

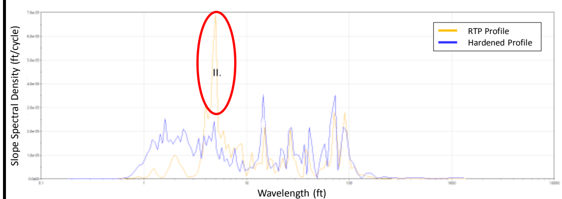
i. Shorter wavelength roughness in the hardened profile is likely from macrotexture (burlap drag and tining) applied behind the GSI sensors.



43

Pennsylvania, I-81

ii. Real-time roughness at the 5’ wavelength was significantly reduced by hand finishing.



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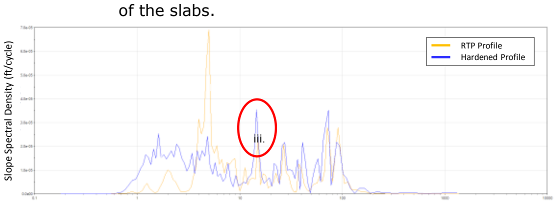
Pennsylvania, I-81

iii. Joint spacing had a larger influence on roughness in the hardened profile than in the real-time profile, this is likely a result of curling and warping of the slabs.



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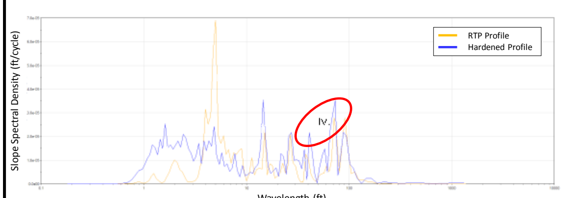
Pennsylvania, I-81

iv. The source of roughness present in the hardened and real-time profiles at longer wavelengths needs additional investigation.



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Iowa, Lyon County L-26

- Ames RTP
- Project Info
  - Mainline overlay paving of county road
  - 5” JPCP over existing HMA
  - 24’ paving width, 6’ x 6’ joint spacing
  - No steel – except in transition sections
  - Stringless paving
  - Concrete deposited in front of paver

SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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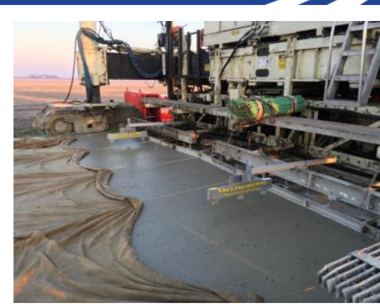
Iowa, Lyon County L-26



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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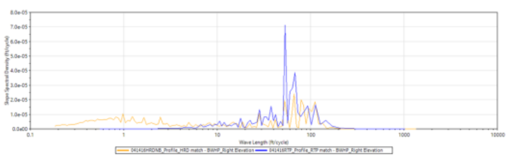
Iowa, Lyon County L-26

- PSD
  - No short wavelength content – no steel, minimal curling/warping due to small slab dimensions
  - 55' wavelength – 3D model?



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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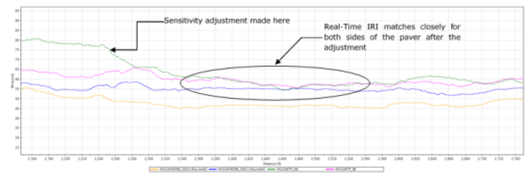
Iowa, Lyon County L-26

- Sensitivity adjustment on the right side of the paver
- What about hardened?



SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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Iowa, Lyon County L-26

- Comparison of real-time and hardened

			RIGHT SIDE OF PAVER		LEFT SIDE OF PAVER			
HARDENED PROFILE SEGMENTS	LENGTH (ft)	MATCHED 0.10 mi SEGMENT #	HRD IRI LT (SB) (in/mi)	RTP IRI LT (SB) (in/mi)	HRD IRI RT (NB) (in/mi)	RTP IRI RT (NB) (in/mi)	Δ RTP-HRD (in/mi) SB	NB
-106+52.00								
-101+24.00	528		88		79			
-95+96.00	528		64		69			
-90+68.00	528	1	50	49	48	55	-1	7
-85+40.00	528	2	69	76	55	90	7	35
-80+12.00	528	3	56	60	46	61	4	15
-74+84.00	528	4	52	54	53	62	2	9
-73+45.00	139		78	78	61	85	0	24
-68+17.00	528		63		67			
-62+89.00	528	5	48	64	48	63	16	15
-57+61.00	528		51		52			
-52+33.00	528	6	57	54	54	71	-3	17
-50+91.00	142		43	58	48	54	15	6
-45+63.00	528	7	53	46	52	62	-7	10
-40+35.00	528	8	59	58	58	67	-1	9
-35+07.00	528	9	51	50	58	60	-1	2
-29+79.00	528		54		51			
-24+51.00	528	10	49	45	57	64	-4	7
-19+23.00	528	11	60	66	65	64	6	-1
-17+38.00	185		52	55	47	45	3	-2
AVERAGE			57.7	58.1	56.2	64.5	2.6	10.9

SHRP2 SOLUTIONS TOOLS FOR THE ROAD AHEAD

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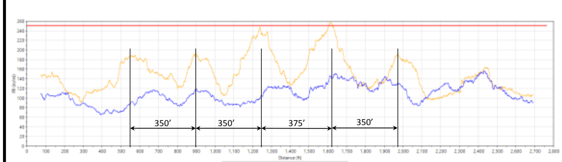
Utah I-15

- IRI on 150 ft base-length from ProVAL
- Matches what we were seeing in real-time the previous night
- IRI cycles up and down every ± 350'? Most pronounced on the right side of the paver, but still present on the left.



52

Utah I-15

- IRI cycles up and down every ± 350'?
- Also shows up in the hardened profile.

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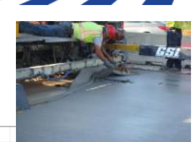
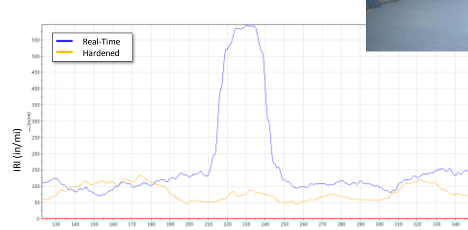
Illinois I-90

- DBI malfunction during paving.
- Do finishers help?





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