

# 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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## **FHWA/SHRP2 CONTACT**

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## **FOR MORE INFORMATION**

[http://www.fhwa.dot.gov/goshrp2/Solutions/Renewal/RO6E/Tools to Improve PCC Pavement Smoothness During Construction](http://www.fhwa.dot.gov/goshrp2/Solutions/Renewal/RO6E/Tools_to_Improve_PCC_Pavement_Smoothness_During_Construction)



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

Session 1: Welcome and Overview

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Federal Highway Administration

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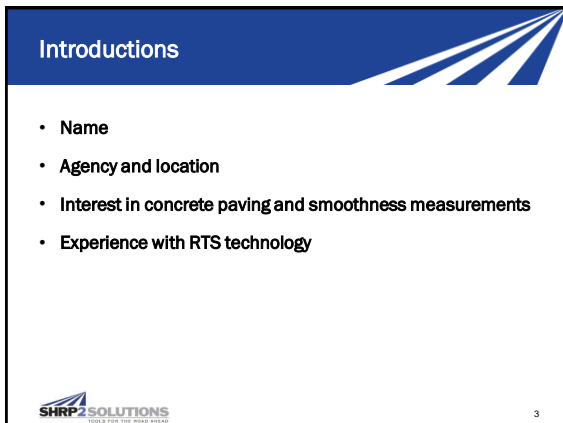


### Session 1: Welcome and Overview

- 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

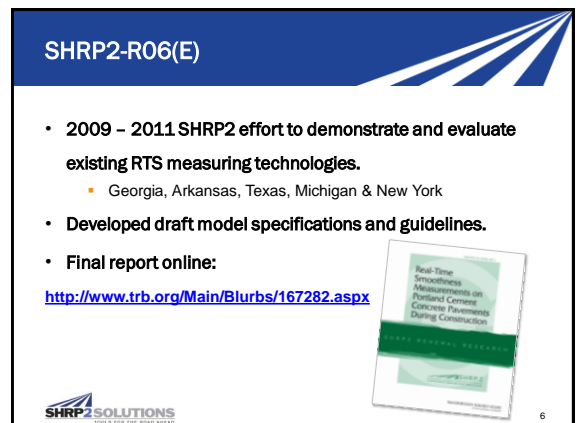
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### SHRP2-R06(E)

- 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

Current effort involves:

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

National Concrete Pavement Technology Center 

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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).

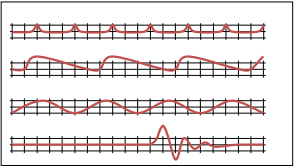


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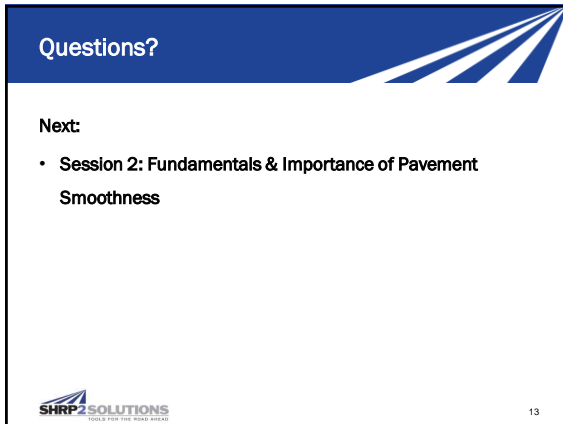
## With RTS Measurements You Can...

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

Session 2: Fundamentals and Importance of Pavement Smoothness




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## 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):


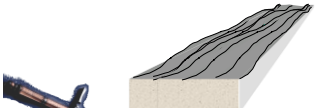
1. Reflects the quality of your work.
2. \$\$\$




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## How do we measure smoothness?

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



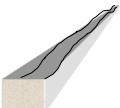
Source: FHWA ProVAL Workshop




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## How do we measure smoothness?

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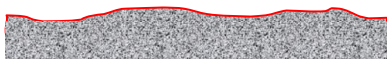
Source: FHWA ProVAL Workshop



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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

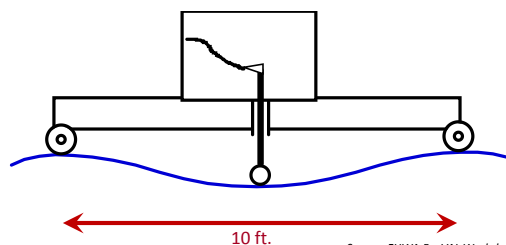
## Measuring Profiles: Rolling Straightedge



Source: FHWA ProVAL Workshop

## Measuring Profiles: Rolling Straightedge

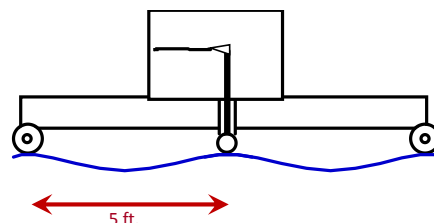
### Rolling Straightedge Response



Source: FHWA ProVAL Workshop

## Measuring Profiles: Rolling Straightedge

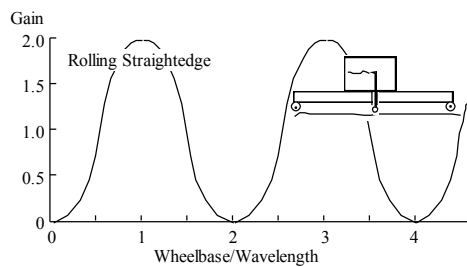
### Rolling Straightedge Response



Source: FHWA ProVAL Workshop

## Measuring Profiles: Rolling Straightedge

### Frequency Response

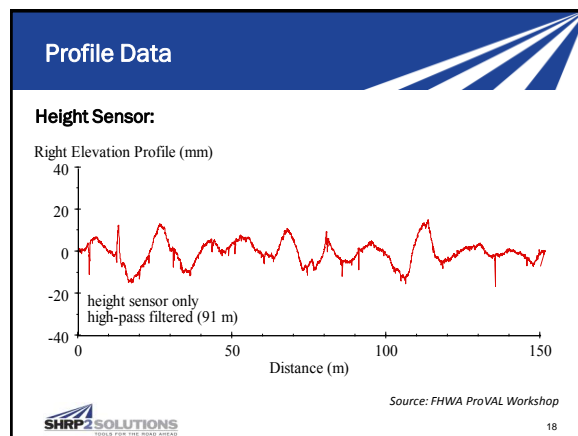
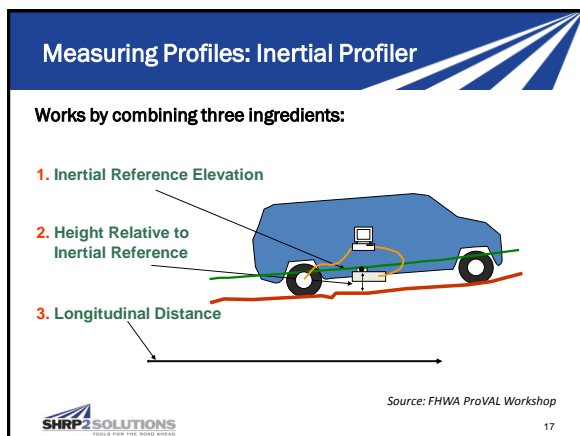
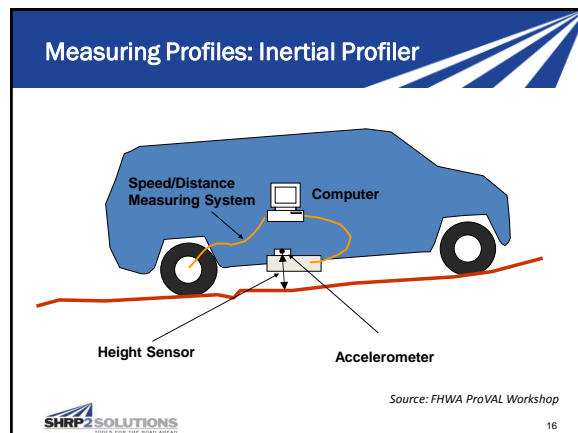
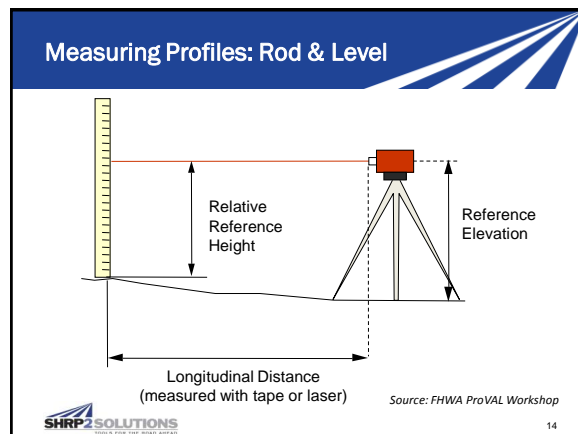
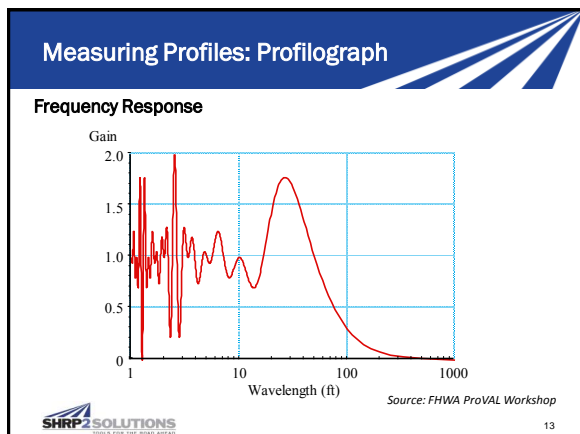


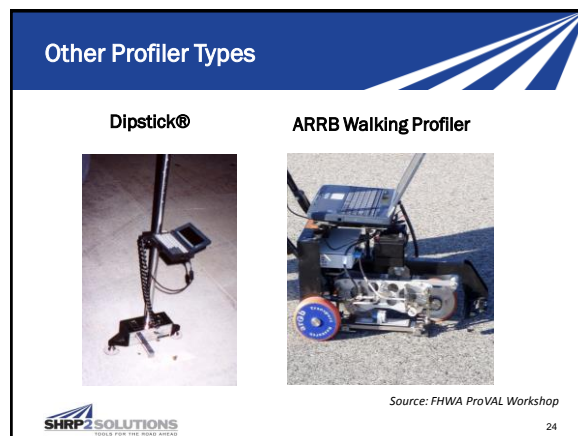
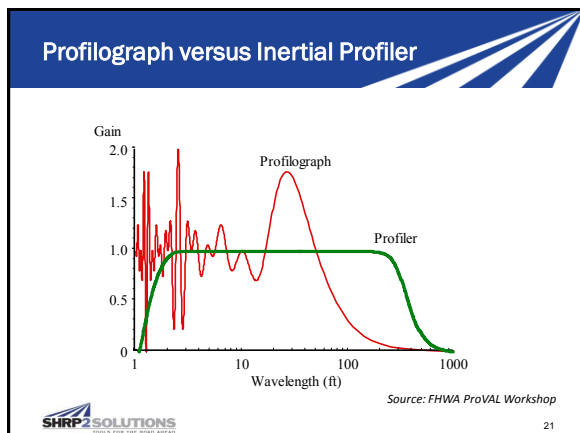
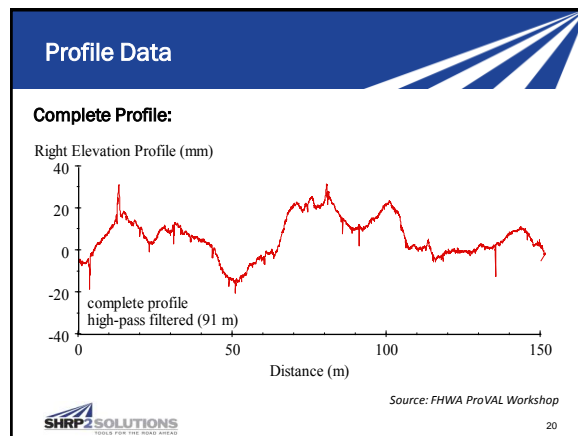
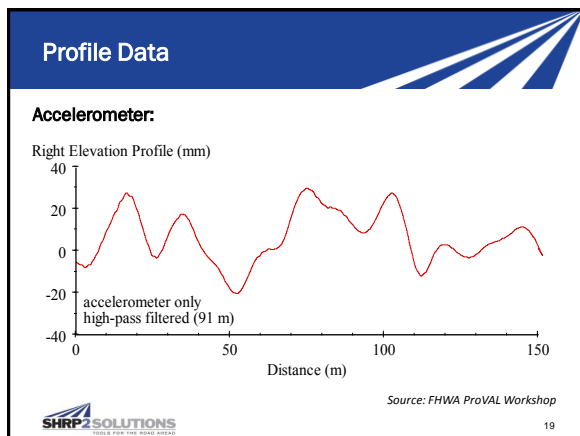
Source: FHWA ProVAL Workshop

## Measuring Profiles: Profilograph



Source: FHWA ProVAL Workshop







### 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)**



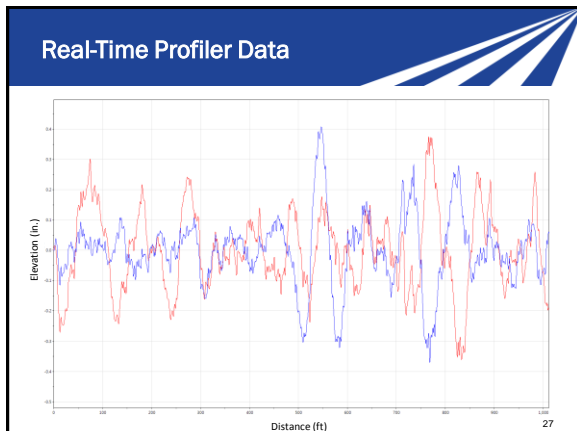
**Ultrasonic Sensors**



**Laser Sensors**

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### 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




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## RTS Profilers

### Ames Engineering Real Time Profiler (RTP)



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## 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.

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## 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).

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## RTS Mounting

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



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## RTS Mounting

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



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## RTS Mounting

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



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## RTS Mounting

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



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## RTS Measurements

- Real-time feedback, viewing and analysis capabilities:



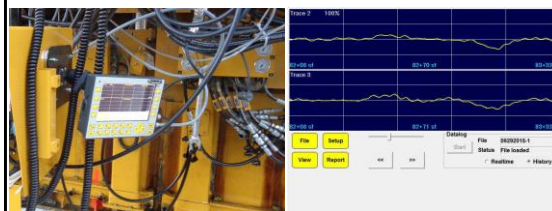
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## RTS Measurements

- Real-time feedback, viewing and analysis capabilities:

GSI



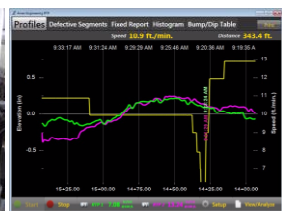
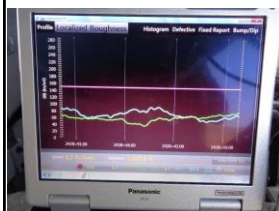
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## RTS Measurements

- Real-time feedback, viewing and analysis capabilities:

Ames RTP



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## 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

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## 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

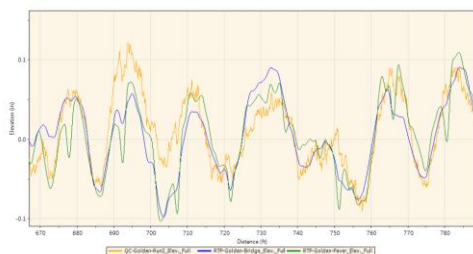
- Why is the real-time profile rougher than the hardened?
  - Fixed height of real-time sensor (no accelerometer)
  - Vibrations from the paver (measurement error) are interpreted as profile deviation
  - Hand finishing removes localized roughness, especially true for higher real-time readings



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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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## 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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## 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

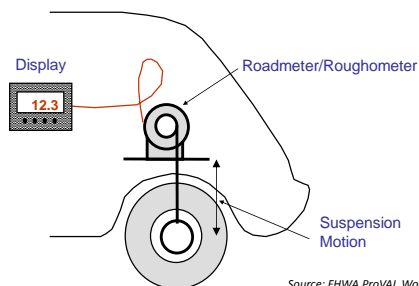


Source: FHWA ProVAL Workshop



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## Response-Type Systems



Source: FHWA ProVAL Workshop



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## Response-Type Systems

### Response-Type Trailer



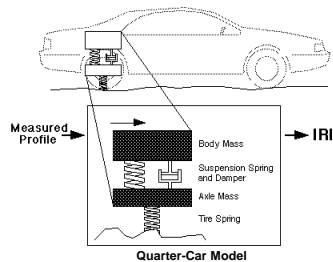
Source: FHWA ProVAL Workshop



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## International Roughness Index (IRI)

### What is IRI?



Source: FHWA ProVAL Workshop



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## International Roughness Index (IRI)

### Quarter-Car Simulation

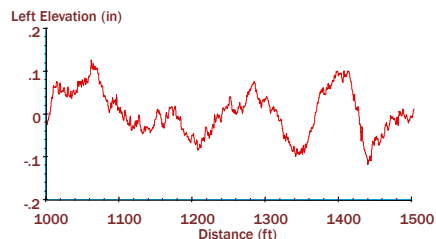


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## Pavement Profile Data

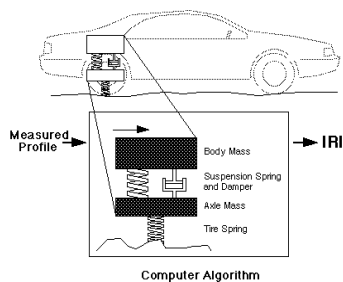


Source: FHWA ProVAL Workshop

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## IRI Computation

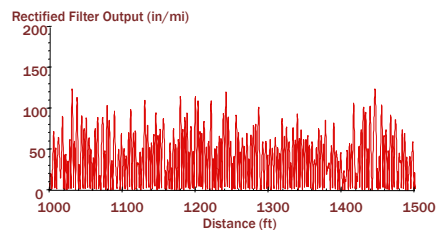


Source: FHWA ProVAL Workshop

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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)

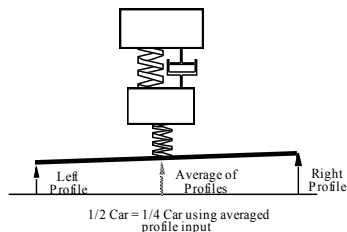
- Calculated from two profiles
- The profiles are averaged point-by-point to create an "average" profile
- The IRI algorithm is applied to the resulting profile

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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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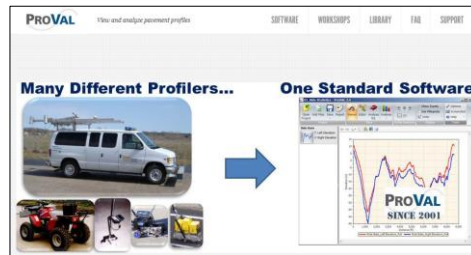
## Localized Roughness

- 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



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## What is ProVAL?

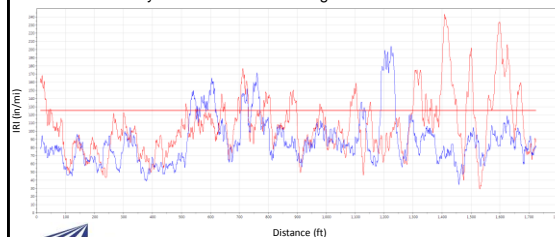
- Software application to view and analyze pavement profiles in many different ways.
- Easy to use and yet powerful to perform many kinds of profile analyses.

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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

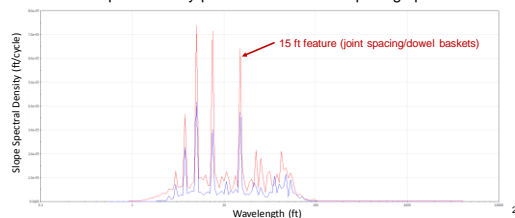
- **Profile Synchronization**
  - Line up repeat profile runs.
- **Smoothness Assurance Module (SAM)**
  - Diamond grinding simulation
  - Side-by-side comparison of profile and roughness



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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.



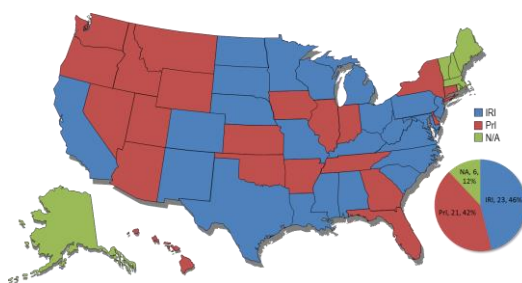
20

### Power Spectral Density (PSD)



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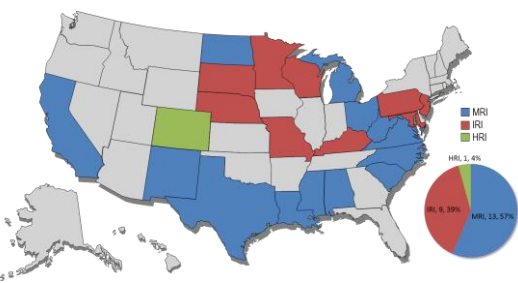
### PCC Pavement Smoothness Specifications



Merritt et al. 2015

22

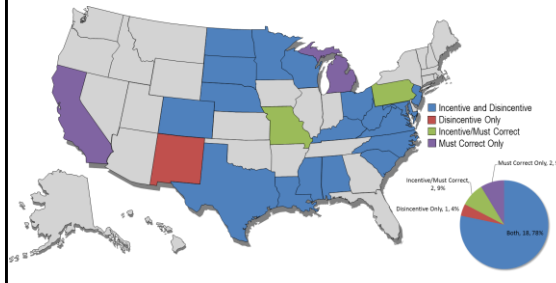
### PCC Pavement Smoothness Specifications



Merritt et al. 2015

23

### PCC Pavement Smoothness Specifications



Merritt et al. 2015

24

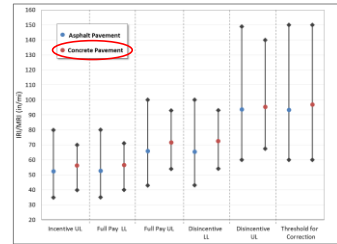
## PCC Pavement Smoothness Specifications

- 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	\$1,000	-\$1,750
	avg.	\$879	-\$900
\$ per lot (SV) 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	\$1,000	-\$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
Profilegraph 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



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Federal Highway Administration



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## Session 5: Best Practices for Concrete Paving Operations

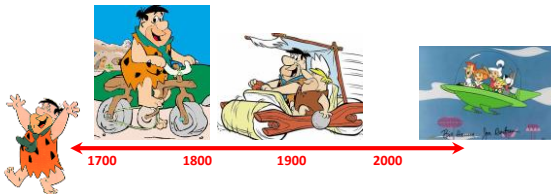
- Key aspects of concrete paving that affect smoothness.
- Importance and potential cost-savings of identifying smoothness issues during construction (real-time).



2

## In the Beginning ...

- A brief history of surface transportation:  
Walking, horse, camel or llama before 1790



3

1924



4

Circa 1950



5

1968



6

2015



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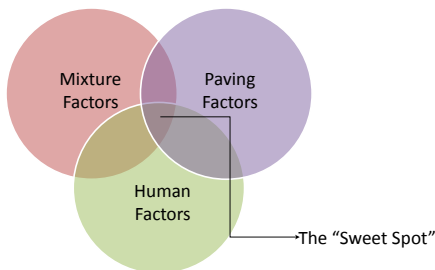
7

## 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.

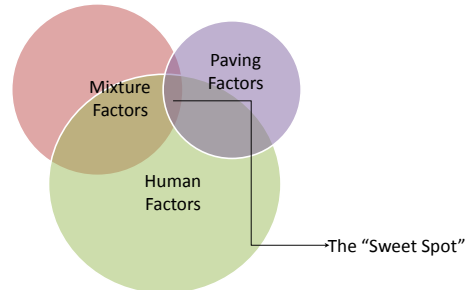
## 21st Century Approach



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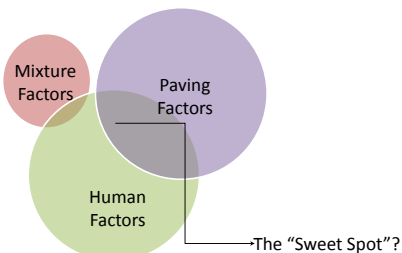
## 21st Century Approach



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## 21st Century Approach



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## Mixture Factors

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



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## Combined Gradation

Remember the purpose of an optimized gradation:

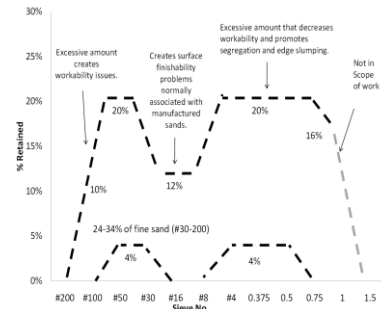
- Economically combining aggregate particles to achieve the desired objectives of:
  - Reduced paste content
  - Improved workability
  - Durability
- An optimized mixture must be workable in the field to achieve durability
- The **Tarantula Curve** was developed concurrently with a lab test that evaluates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



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## Combined Gradation: The Tarantula curve

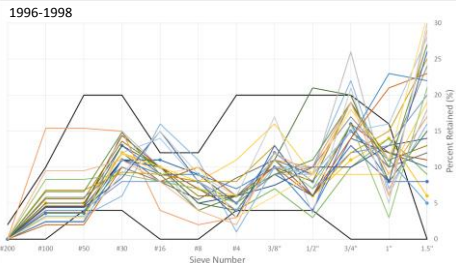


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## Combined Gradation: Tarantula Curve Validation

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

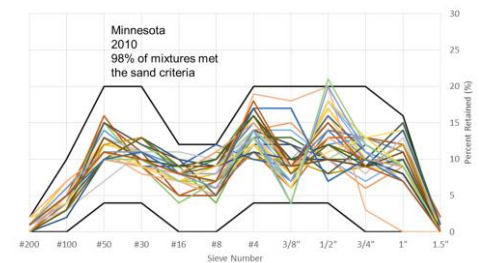


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## Combined Gradation: Tarantula Curve Validation

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.

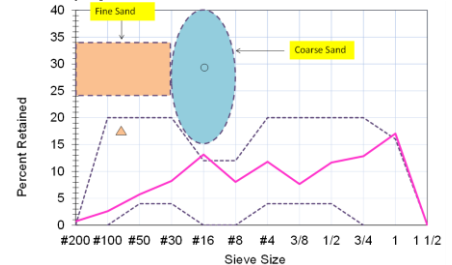


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## Combined Gradation Tarantula Curve Example

FHWA mobile lab - project A



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Images from Jagan Gudimettla 18



## Combined Gradation Tarantula Curve Example

FHWA mobile lab – project A

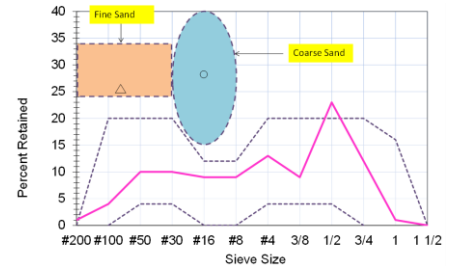


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Images from Jagan Gudimettla 19

## 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



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## Track Line



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## Stringline

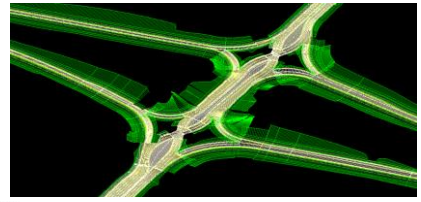
- Adjusted for smoothness
- Properly and uniformly tensioned
- Pin spacing



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## Stringless Model

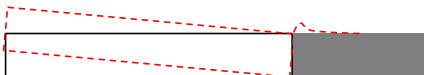
- Smooth transitions
- Point spacing or true curves
- Control points



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## Paver Setup

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



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## Paver Setup

- Sensitivities
  - Sensors
  - Stringless



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## 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

plow  
metering  
gate/strikeoff  
head in grout  
box



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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?



## Human Factors

- Training
- Experience
- Communication
- Empowerment



## Human Factors

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



## Human Factors

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



## 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



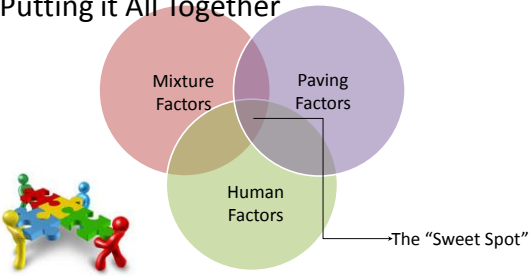
## Human Factors

- Empowerment
  - Encourage innovation
  - Enable decision making



### Summary of Best Practices

#### Putting it All Together



Mixture Factors

Paving Factors

Human Factors

→The "Sweet Spot"

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### Questions?

**Next:**

**Sessions 6: Using RTS Technology to Improve Concrete Pavement Smoothness**

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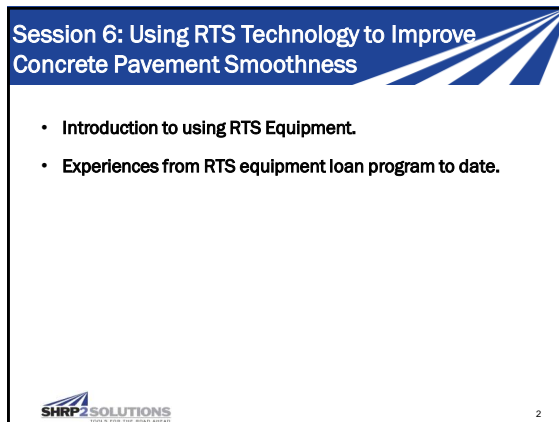
## Using Real-time Smoothness Measurements to Improve Concrete Pavement Quality and Save Money

Session 6: Using RTS Technology to Improve Concrete Pavement Smoothness

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Federal Highway Administration

AASHTO  
American Association of State Highway and Transportation Officials

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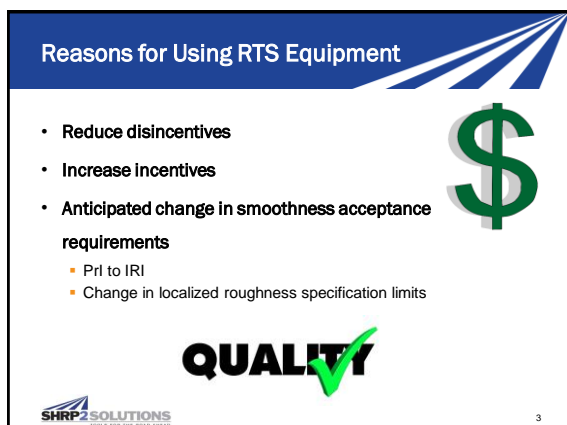


## Session 6: Using RTS Technology to Improve Concrete Pavement Smoothness

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

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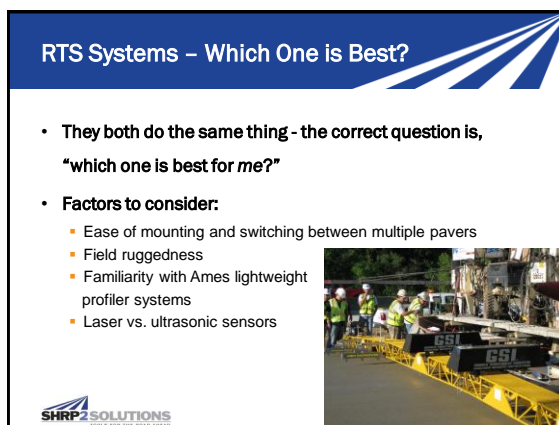
## Reasons for Using RTS Equipment

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

**QUALITY** ✓


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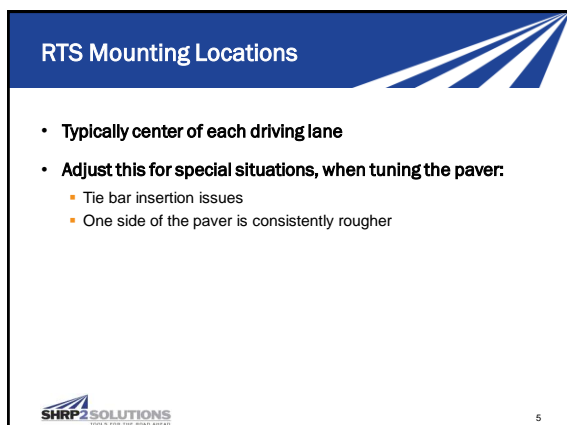


## RTS Systems – Which One is Best?

- 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



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## 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

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## RTS Mounting Locations



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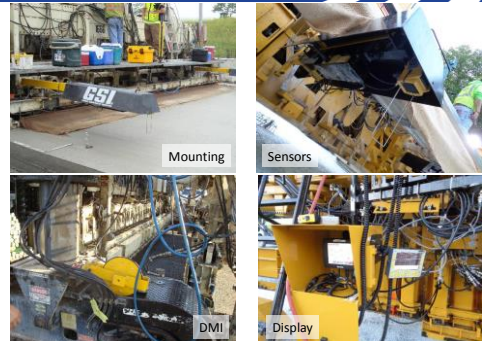
## RTS Systems: Daily Setup and Shutdown

- **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



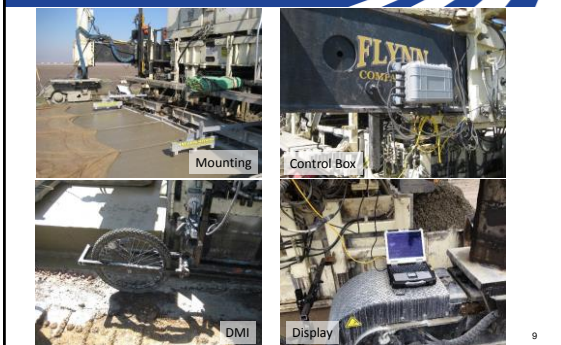
7

## RTS Systems: GOMACO GSI Setup



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## RTS Systems: Ames RTP Setup



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## 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.



## 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

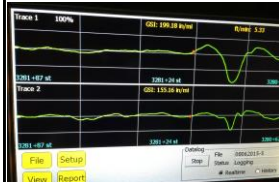



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## Localized Roughness Events

- Running the paver out of concrete

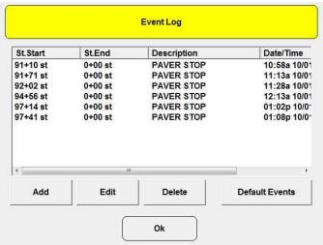



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## Localized Roughness Events

- Stopping the paver



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+06 st	0+00 st	PAVER STOP	12:13a 10/01
97+14 st	0+00 st	PAVER STOP	01:02p 10/01
97+41 st	0+00 st	PAVER STOP	01:08p 10/01


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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.



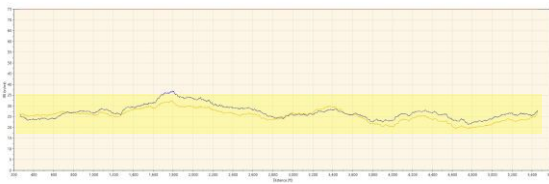
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## Overall Smoothness

- Stay focused and incredible things can happen

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



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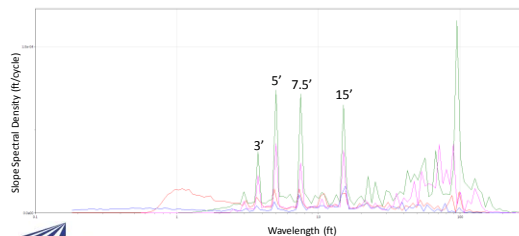
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## Using RTS Systems

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

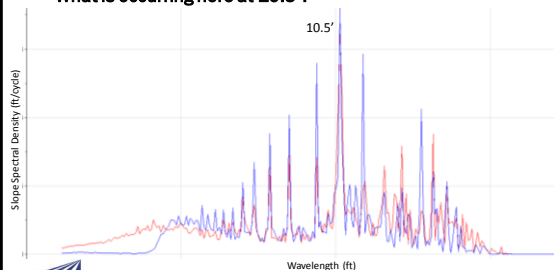
## Repeating Features

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



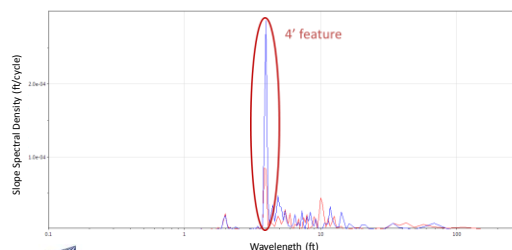
## Repeating Features

- What is occurring here at 10.5'?



## Repeating Features

- CRCP – what is contributing to roughness here?



## 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

## 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.



## Idaho, I-84

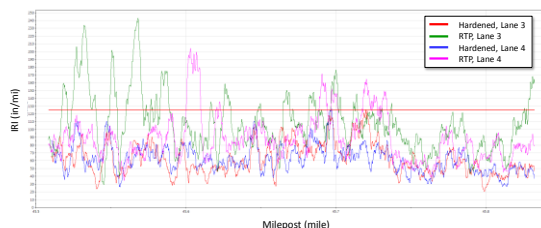
- **Monitoring (4 days of paving)**
  - Paver stops/starts
  - Concrete load consistency (wet/dry loads)
  - Concrete head in front of paver
  - Concrete level in grout box
  - Use of auto-float
- **Hardened profile data collected the day following paving.**

## Idaho, I-84



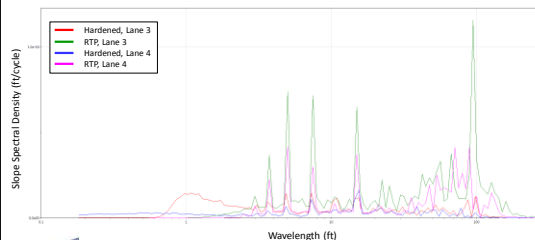
## Idaho, I-84

- **RTP consistently measured higher roughness than hardened.**



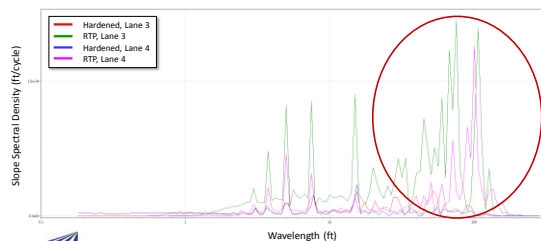
## Idaho, I-84

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



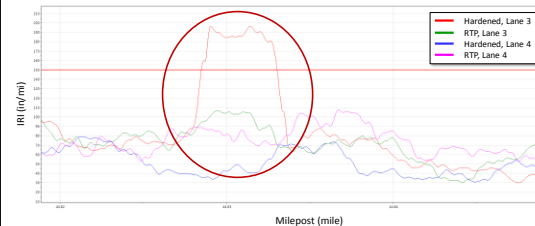
## Idaho, I-84

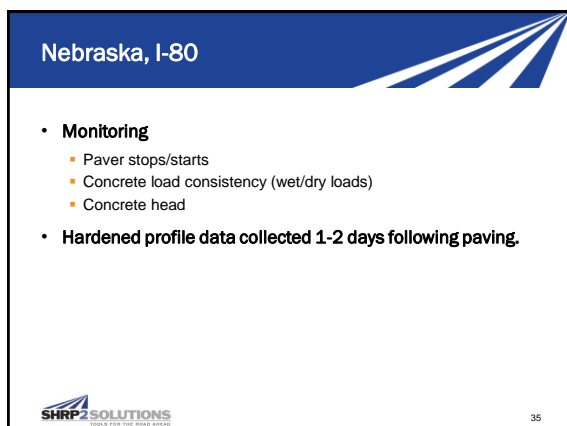
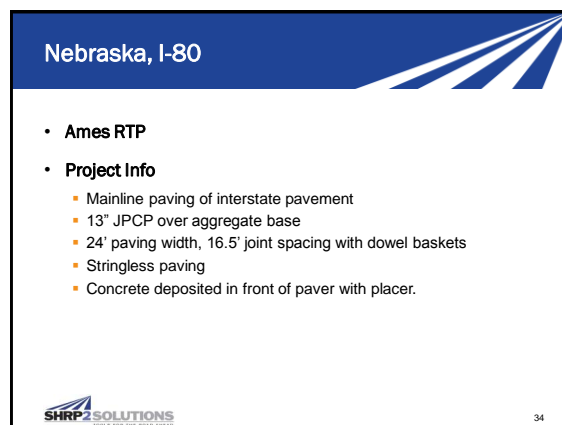
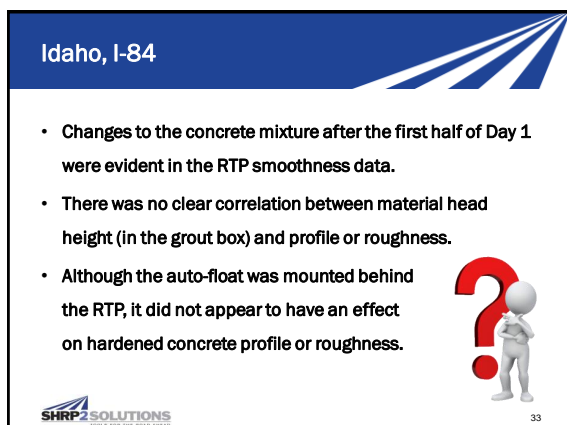
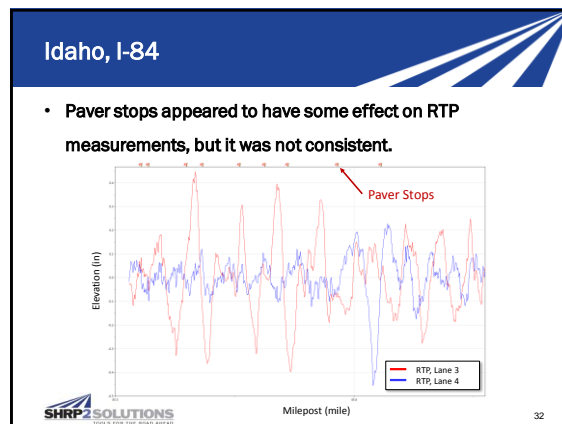
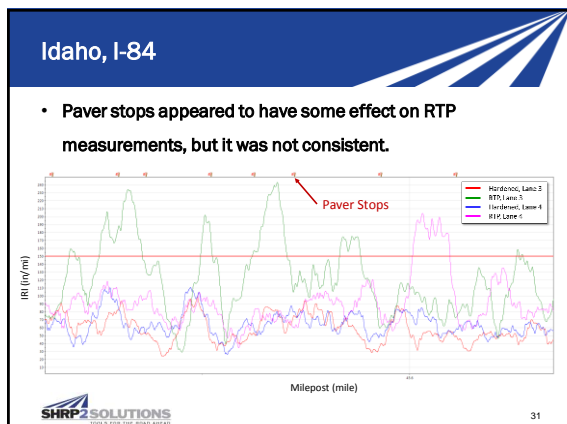
- **Longer wavelength content (~40-100 ft) in RTP but not in hardened profiles - cause is unknown.**



## Idaho, I-84

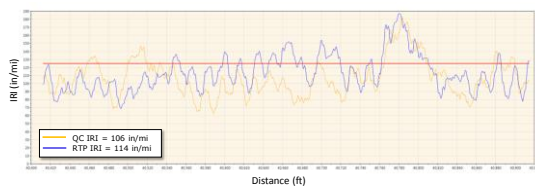
- **Instance of roughness feature introduced into profile after RTP measurement.**





## Nebraska, I-80

- RTP showed only slightly higher IRI than hardened profiles.

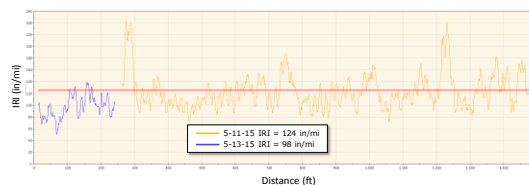


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## Nebraska, I-80

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

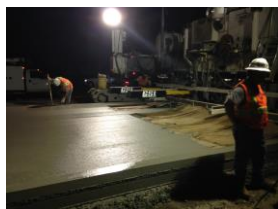


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## Texas, SH99

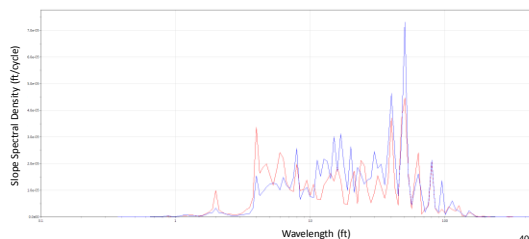
- GOMACO GSI
- Project Info
  - Paving of new mainline pavement
  - 12" CRCP over asphalt base



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## Texas, SH99

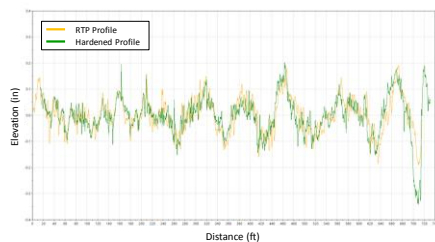
- PSD content was sporadic on days with poor smoothness results.



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## Pennsylvania, I-81

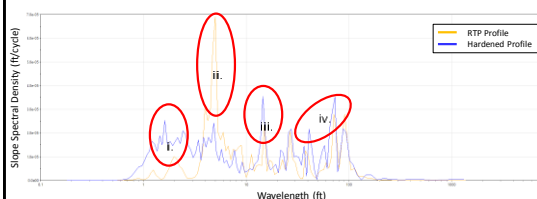
- Real-time and hardened profiles parallel each other
- 20 in/mi difference



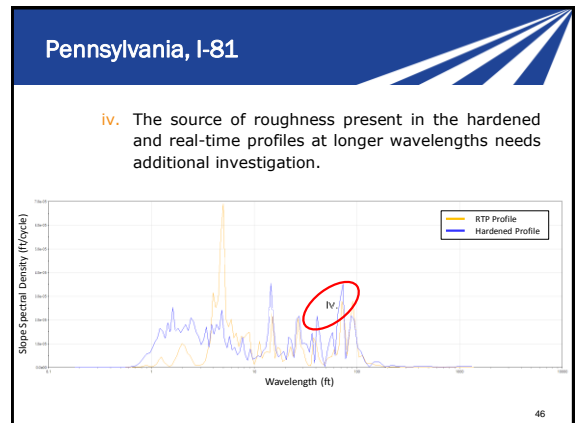
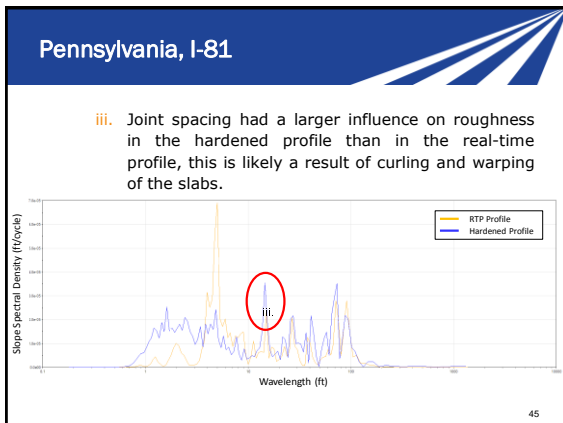
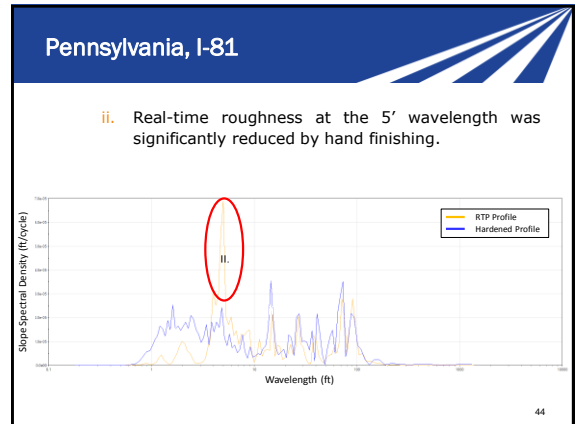
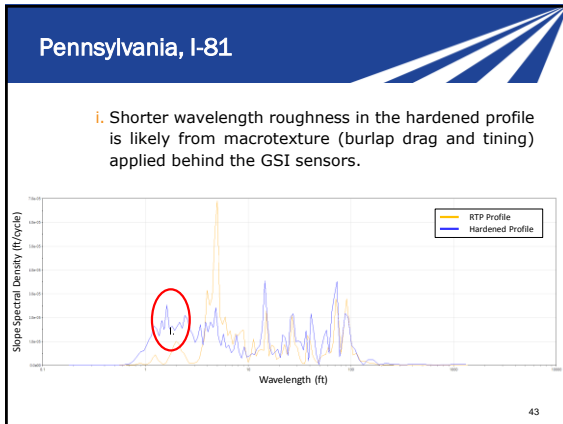
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## Pennsylvania, I-81

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



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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

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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?

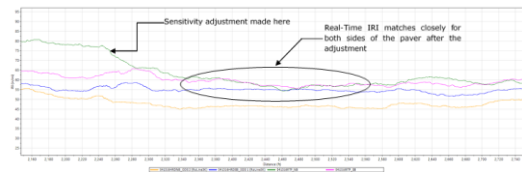


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## Iowa, Lyon County L-26

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



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## Iowa, Lyon County L-26

### • Comparison of real-time and hardened

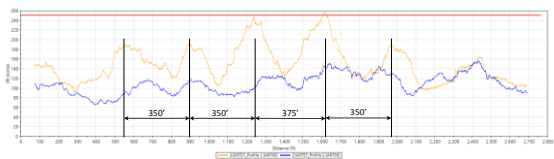
HARDENED PROFILE SEGMENTS	LENGTH (ft)	MATCHED 0.10 ft SEGMENT #	RIGHT SIDE OF PAVEMENT		LEFT SIDE OF PAVEMENT		Δ RTP-HRD (in/m)	
			HRD (in/m)	RTP (in/m)	HRD (in/m)	RTP (in/m)	SR	NR
-106+52.00								
-101+24.00	528		88		79			
-99+96.00	528		84		69			
-90+68.00	528	1	50	49	48	55	-1	7
-85+40.00	528	2	69	76	55	60	7	25
-80+12.00	528	3	56	60	46	61	4	15
-74+84.00	528	4	52	54	53	62	2	9
-71+53.00	1378		78	78	61	65	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	56	56	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

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## Utah I-15

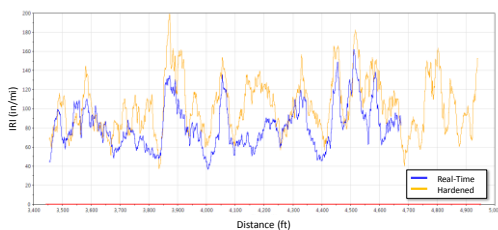
- IRI on 150 ft base-length from ProVAL
- Matches what we were seeing in real-time the previous night
- IRI cycles up and down every  $\pm 350'$ ? Most pronounced on the right side of the paver, but still present on the left.



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## Utah I-15

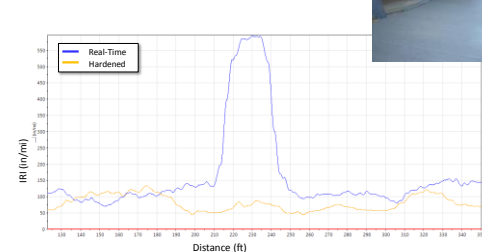
- IRI cycles up and down every  $\pm 350'$
- Also shows up in the hardened profile.



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## Illinois I-90

- DBI malfunction during paving.
- Do finishers help?



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## Using RTS Systems

### Summary

- Step 1 – Establish a baseline
- Step 2 – Eliminate big events
- Step 3 – Process adjustments
- Step 4 – Mitigate repeating events when possible
- Focus on continuous improvement and great things are possible.



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## Workshop Summary

- ✓ We discussed the importance of pavement smoothness and fundamentals of smoothness measurement.
- ✓ We discussed the IRI and current practices for IRI-based specifications.
- ✓ We discussed best practices for concrete paving operations to achieve ride quality requirements.
- ✓ We demonstrated how Real-Time Smoothness technology can be used as a tool for improving concrete pavement smoothness.

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## Questions?



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TOOLS FOR THE ROAD AHEAD

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