EL05-2015 **Implementation Assistance Program**

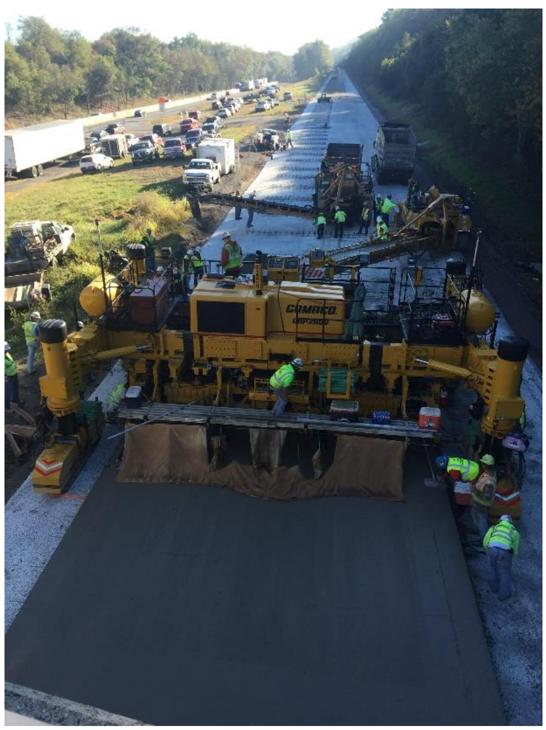
Tools to Improve PCC Pavement Smoothness During Construction (R06E)

Seeking widespread adoption of the real-time smoothness (RTS) technology by contractors and agencies who routinely construct PCC pavements will be achieved through:

1. Equipment Loan Program
2. Showcases
3. Workshops
4. Case studies/results Documentation
5. Specification Refinement
6. Marketing & Outreach

SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

National Concrete Pavement Technology Center



FIELD REPORT: PENNSYLVANIA EQUIPMENT LOAN

U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO The Voice of Transportation

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

INTRODUCTION

The Federal Highway Administration (FHWA) has contracted with the National Center for Concrete Pavement Technology (CP Tech Center) for *Implementation Support for Strategic Highway Research Program II (SHRP2) Renewal R06E Real-time Smoothness Measurements on Portland Cement Concrete Pavements During Construction*. One of the tasks included in this contract is equipment loans to contractors. This task involves facilitating the loan of real-time smoothness equipment for field trial use on 11 designated PCC pavement construction projects. The scope of this task includes the following activities:

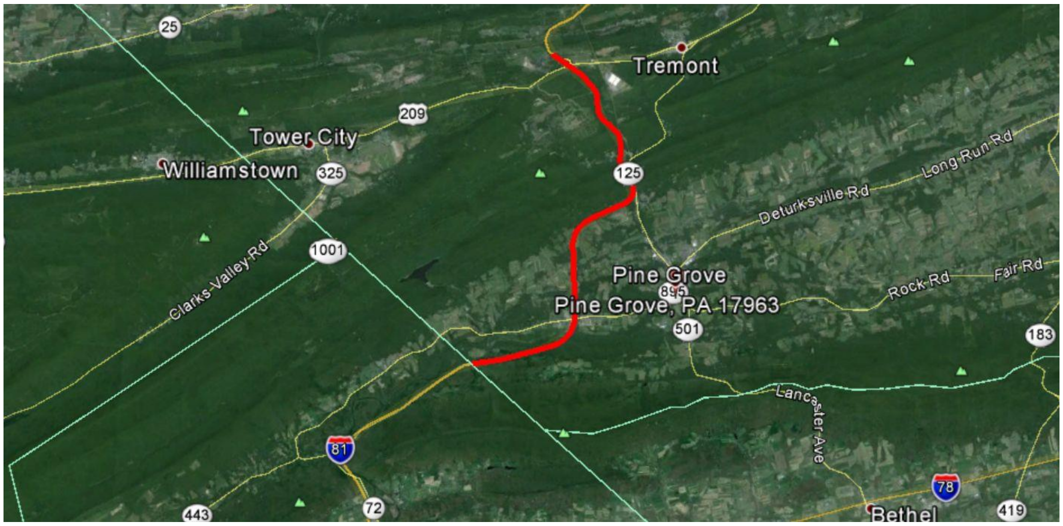
- Provide equipment (GOMACO GSI or Ames RTP) and labor for a field trial of 10 to 30 paving days
- Provide technical assistance for equipment installation start-up and operation
- On-call technical support throughout the duration of the field trial
- Planning, coordination and execution of the field trials
- Contact the recipient within 5 days of notice to proceed from the COR
- On-site support for at least 2 weeks
- Maintain a master list of field trial participants and update the list quarterly

This report summarizes the activities and findings of the equipment loan conducted in Pennsylvania.

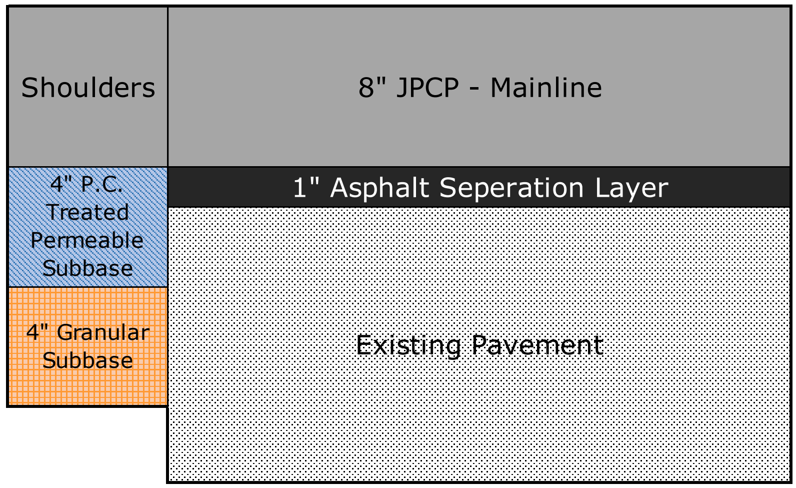
PROJECT DETAILS

The equipment loan was performed in September/October 2015 on a project near Pine Grove, PA. Table 1 summarizes the pertinent project details.

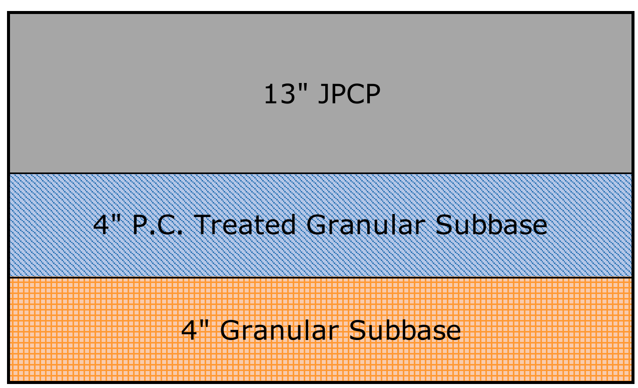
Table 1. Pine Grove, PA, I-81 Project Information

Item	Details
Project Location	Mainline paving located in the northbound lanes of I-81 south of the Pine Grove exit (red line denotes the approximate project limits). 
Route	I-81
Agency	Commonwealth of Pennsylvania Department of Transportation (PennDOT)
Paving Contractor	Hi-Way Paving, Inc.

<table>
<tr><th>Item</th><th>Details</th></tr>
<tr><td>Paving Equipment</td><td>Gomaco 2800 paver, Leica stringless machine control, CMI MTP and Gomaco RTP placers</td></tr>
<tr><td>Real-Time System</td><td>Gomaco GSI</td></tr>
<tr><td>Typical Sections</td><td>Unbonded Overlay: 8” JPCP on 1” nominal asphalt separation layer



Reconstruction Transitions: 13” JPCP on 4” Treated Permeable Subbase on 4” Granular Subbase



</td></tr>
<tr><td>Joint Spacing</td><td>Transverse: 15’ c/c (some variable spacing to offset new joints from existing underlying joints)

Longitudinal spaced at 12’ with tie bars inserted</td></tr>
<tr><td>Gomaco GSI Setup</td><td>Paver width = 24’

Sensor #1: approximate left wheel path of driving lane (8’-1” off of 4’ shoulder longitudinal joint)
Sensor #2: approximate right wheel path of driving lane (8’-8” off of 12’ shoulder longitudinal joint)</td></tr>
<tr><td>Miscellaneous Details</td><td>A vibrator monitor was in use, vibrators were operated in the range of 7,000 to 10,000 vpm.

Burlap drag behind the finishing pan.

Hand finishing consisted of a 12’ straightedge and 10’ float.</td></tr>
</table>

Item	Details
	Final surface texture consisted of a burlap drag followed by transverse tining. Corrective action required for any 0.10 mile extent with an IRI exceeding 70 in/mi and bumps exceeding ¼″ in 10′.

IMPLEMENTATION ACTIVITIES

On-site coordination with the contractor began on September 15, 2015 with installation of the Gomaco GSI on September 16 and 17, 2015. Paving was delayed for a period to adjust the 3D model for revised cross-slopes. Collection of real-time profile data began on September 24, 2015 and continued through October 1, 2015. This equipment loan was performed with a GSI unit provided by Gomaco, the contractor was allowed to continue using the GSI for all of the northbound mainline paving which extended beyond the timeframe of the SHRP2 implementation team's on-site technical support.

Table 2 provides a summary of the R06E team's on-site technical support activities.

Table 2. Summary of R06E On-Site Activities

Date	On-Site Implementation Activites
15SEP2015	Contractor coordination and preparation for install.
16SEP2015	GSI Installation 7:30 am to 2:30 pm.
17SEP2015	Complete installation of the GSI 7:30 am to 4:30 pm.
18SEP2015	GSI calibration.
24SEP2015	Real-time profile data collection, 6:30 am to 5:30 pm from approximately 0+70 to 7+50. Data logging failure due to a hardware issue.
25SEP2015	Install new GSI computer, real-time profile data collection, 6:00 am to 6:30 pm from approximately 16+53 to 34+98.
26SEP2015	Real-time profile data collection, 6:00 am to 4:30 pm from approximately 35+18 to 56+82.
27SEP2015	No work.
28SEP2015	Real-time profile data collection by the contractor, from approximately 57+07 to 78+95.
29SEP2015	Real-time profile data collection by the contractor, from approximately 79+18 to 89+01.
30SEP2015	No work (rain).
01OCT2015	Real-time profile data collection, 6:30 am to 1:30 pm from approximately 89+33 to 101+94 (rain shortened).

OBSERVATIONS, DATA and ANALYSES

PennDOT is a lead adopt state for this implementation effort, this project was chosen for an equipment loan through coordination with PennDOT, Gomaco and Hi-Way Paving, Inc. Paving operations were observed to be quality conscious and efficient, although production was limited by constraints which prevented the construction of a haul road wide enough to allow batch trucks to pass by the paving operation.

Figures 1 through 6 illustrate the installation of the GSI and different aspects of the paving equipment and processes used by Hi-Way.


Figure 1. Gomaco GSI Mounted to 2800 Paver


Figure 2. Concrete Spreading by Placers Ahead of the Slipform Paver


Figure 3. Concrete Placement at the Front of the Paver


Figure 4. Typical Hand Finishing Behind the Paver


Figure 5. Isolated Areas of Mixture Exhibited Poor Finishing Characteristics


Figure 6. Close-up of Profile Feature Created by a Paver Stop (mitigated by hand finishing)

CONCRETE MIXTURE

Initial smoothness is sensitive to the workability and uniformity of the concrete mixture. The mixture proportions used by Hi-Way are shown in Table 3.

Table 3. I-81 Concrete Mixture Proportions

REAL-TIME SMOOTHNESS IMPLEMENTATION

Mix Design & Proect Info.

General Information	
Project:	PENNSYLVANIA I-81
Contractor:	HI-WAY
Mix Description:	SLIPFORM MAINLINE
Mix ID:	15-213-2
Date(s) of Placement:	

Cementitious Materials	Source	Type	Spec. Gravity	lb/yd^3	% Replacement by Mass
Portland Cement:	KEYSTONE - BATH	1	3.150	500	
GGBFS:					
Fly Ash:	ASH VENTURES - BELEW NC	F	2.320	88	14.97%
Silica Fume:					
Other Pozzolan:					
				588	**lb/yd^3**
				6.3	**sacks/yd^3**

Aggregate Information	Source	Type	Spec. Gravity SSD	Absorption (%)	% Passing #4
Coarse Aggregate:	FOSTER - HIGGINS		2.650	n/a	n/a
Intermediate Aggregate:				n/a	n/a
Fine Aggregate #1:	FOSTER - HIGGINS		2.640	n/a	n/a
Fine Aggregate #2:					

Coarse Aggregate %:	60.5%
Intermediate Aggregate %:	
Fine Aggregate #1 % of Total Fine Agg.:	100.0%
Fine Aggregate #2 % of Total Fine Agg.:	
Fine Aggregate #1 %:	39.5%
Fine Aggregate #2 %:	

Mix Proportion Calculations	
Water/Cementitious Materials Ratio:	0.430
Air Content:	6.00%

	Volume (ft3)	Batch Weights SSD (lb/yd3)	Spec. Gravity	Absolute Volume (%)
Portland Cement:	2.544	500	3.150	9.421%
GGBFS:				
Fly Ash:	0.608	88	2.320	2.251%
Silica Fume:				
Other Pozzolan:				
Coarse Aggregate:	11.002	1,819	2.650	40.749%
Intermediate Aggregate:				
Fine Aggregate #1:	7.174	1,182	2.640	26.571%
Fine Aggregate #2:				
Water:	4.052	253	1.000	15.007%
Air:	1.620			6.000%
	27.000	**3842**		**100.000%**
	Unit Weight (lb/ft^3)	**142.3**		

Admixture Information	Source/Description	oz/yd3	oz/cwt
Air Entraining Admix.:	MB AE 90	5.90	1.00
Admix. #1:	MB POZZ 80	23.50	4.00
Admix. #2:	PREMEIRE PROLONG L		
Admix. #3:			

Combined gradation data is provided in Table 4 and Figures 7 and 8.

Table 4. QC Sieve Analysis Data

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REAL-TIME SMOOTHNESS IMPLEMENTATION

Combined Gradation Test Data

Project: PENNSYLVANIA I-81
Mix ID: MAINLINE SLIPFORM - 15-213-2
Sample Comments: MIX DESIGN FROM HI-WAY
Test Date: AVERAGE OF 22 COARSE & 21 FINE SAMPLES

Total Cementitious Material: 588 lb/yd^3

Agg. Ratios: 60.53% 39.47% 100.00%

Sieve	Coarse	Intermediate	Fine #1	Fine #2	Combined % Retained	Combined % Retained On Each Sieve	Combined % Passing
2 ½"	100%		100%		0%	0%	100%
2"	100%		100%		0%	0%	100%
1 ½"	100%		100%		0%	0%	100%
1"	98%		100%		1%	1%	99%
¾"	*73%*		100%		16%	15%	84%
½"	47%		100%		32%	16%	68%
⅜"	*35%*		100%		39%	7%	61%
#4	24%		100%		46%	7%	54%
#8	5%		91%		61%	15%	39%
#16	*4%*		64%		72%	11%	28%
#30	*3%*		42%		82%	9%	18%
#50	*2%*		21%		91%	9%	9%
#100	*1%*		7%		97%	6%	3%
#200	0.8%		3.0%		98.3%	1.7%	1.7%

Workability Factor: **39.6**
Coarseness Factor: **64.4**

36% Coarse Sand
26% Fine Sand

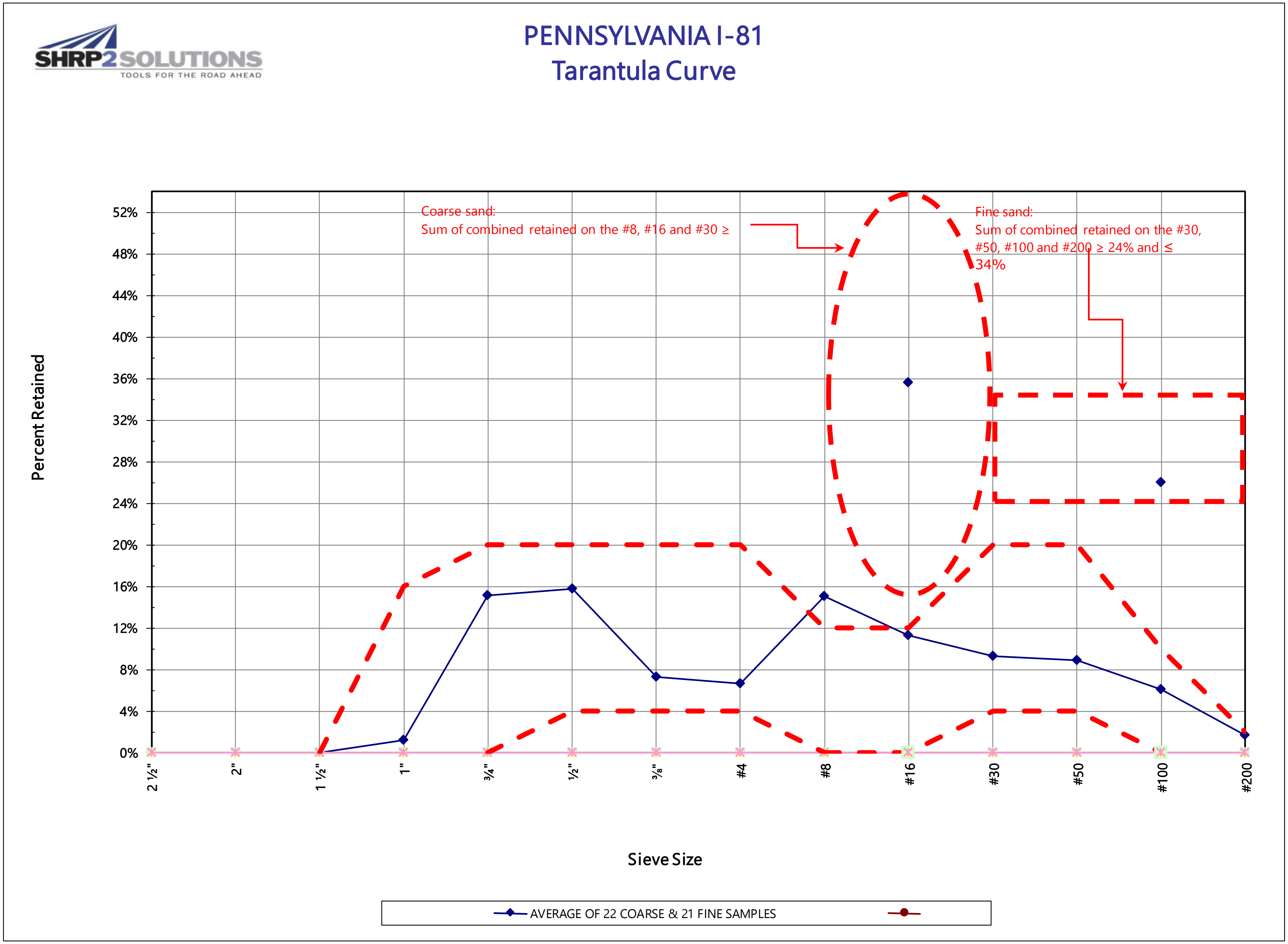

Figure 7. I-81 Combined Percent Retained (Tarantula Curve)

PENNSYLVANIA I-81

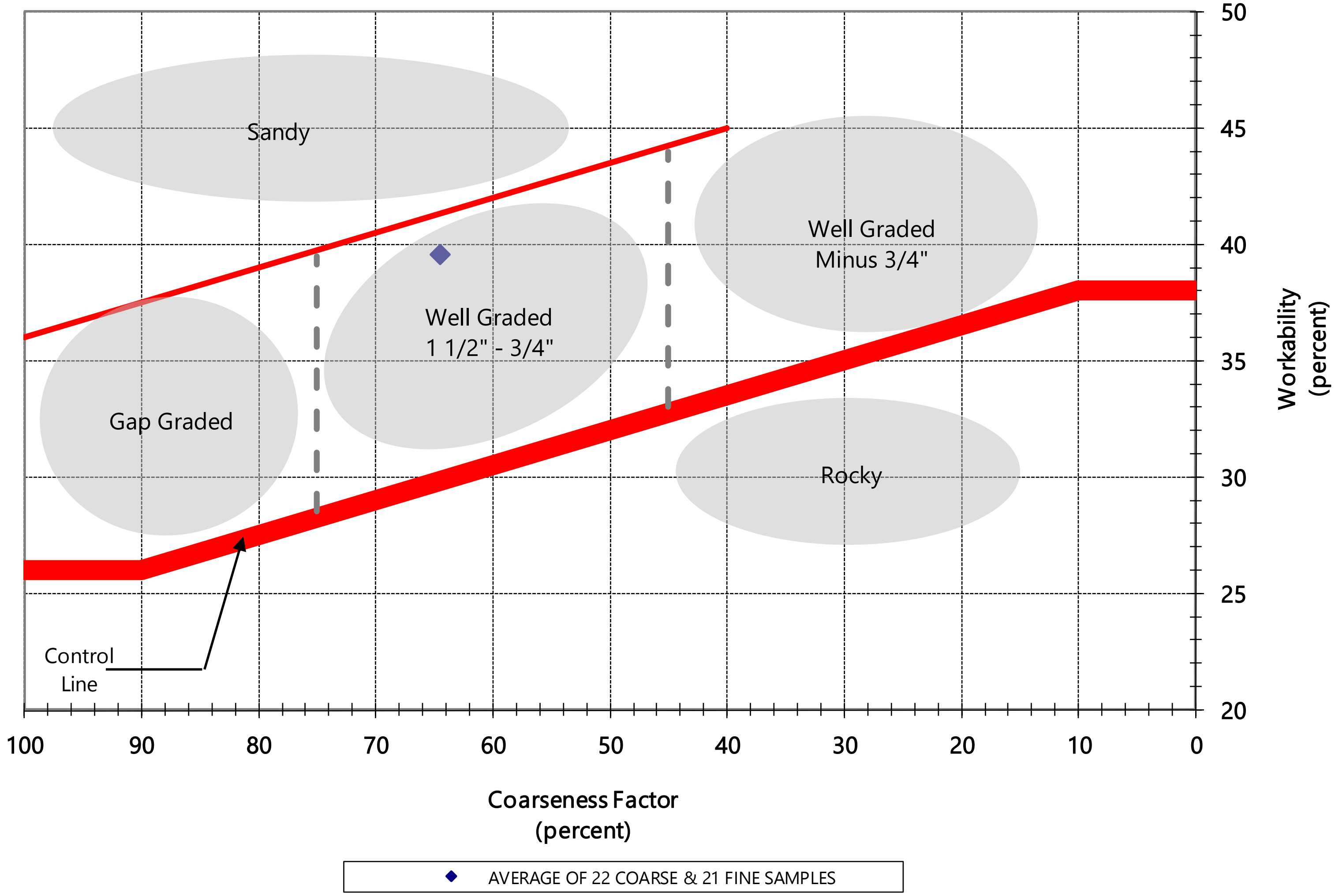

Figure 8. I-81 Combined Gradation Coarseness and Workability Factors

PROFILE CHARCTERISTICS

The following information is provided to illustrate how real-time smoothness systems can be used as a tool to improve the initial smoothness of concrete pavements.

Real-Time Smoothness (RTS) vs. Hardened QC Profile

A tabular comparison of hardened and real-time smoothness results is shown in Table 5.

Table 5. Summary of Overall IRI Results (see Figure 9 for a schematic of profile locations)

	Hardened QC IRI (in/mi)		Real-Time GSI IRI (in/mi)			
Date	Passing Lane (lt/rt/avg)	Truck Lane (lt/rt/avg)	Passing Lane	Truck Lane	**Limits (Hi-Way File)**	**Length (ft)**
25SEP2015	79/65/72	73/80/77	92	74	16+53 to 29+78 (7-8-9)	1,325
25SEP2015	82/80/81	76/79/78	98	76	29+78 to 34+98 (10)	520
26SEP2015	73/83/78	72/82/77	100	85	35+18 to 40+34 (11)	516
26SEP2015	78/84/81	77/87/82	99	96	40+34 to 56+18 (12-13-14)	1,584
28SEP2015	76/72/74	68/76/72	95	83	57+07 to 72+02 (15-16-17)	1,495
28SEP2015	84/86/85	67/74/71	105	67	72+02 to 79+18 (18-19-20)	716
29SEP2015	67/72/70	70/85/78	90	83	79+18 to 87+86 (18-19-20)	868
	no hardened data		63	71	89+33 to 101+94	1,261
Weighted Average	77	77	91	80		8,285

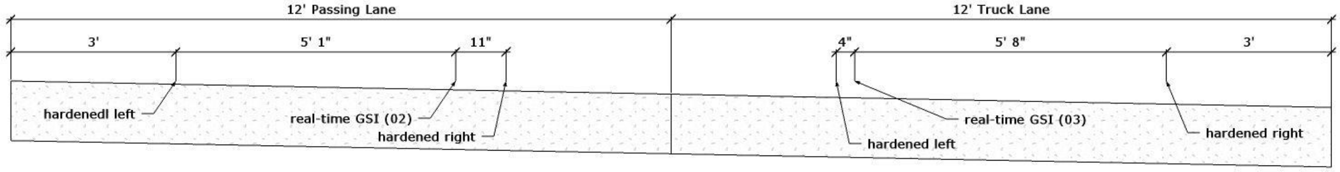

Figure 9. Lateral Locations of Profile Data

Observations and Discussion of Real-Time vs. Hardened IRI Results

1) Real-time results in the passing lane are on average 11 in/mi greater than the real-time results in the truck lane.
   a. Note that the two GSI profiles are separated laterally by approximately 7’-3” and the hardened profiles are separated by 6’-0”. While the difference in IRI between the GSI profiles is greater than the hardened profiles, there are instances where the hardened profiles within the same lane differ by as much as 15 in/mi.
   b. Using ProVAL analysis tools to compare and contrast between sections where the difference between GSI results was greatest (28SEP2015 72+02 to 79+18) and least (26SEP2015 40+34 to 56+18), the following can be inferred:
      i. The magnitude of profile deviation (dips and bumps) for the passing lane on 28SEP2015 is visibly greater than the truck lane (Figure 10), while the same comparison for 26SEP2015 shows a much closer agreement between the raw profile data (Figure 11).
      ii. Looking at the same profiles, the power spectral density (PSD) analyses show that the difference in roughness between the passing lane and truck lane is coming from multiple wavelengths relevant to IRI (3-100 ft range) on

28SEP2015 (Figure 12), whereas on 26SEP2015 (Figure 13) the contribution from various wavelengths is very similar for the passing lane and truck lane.

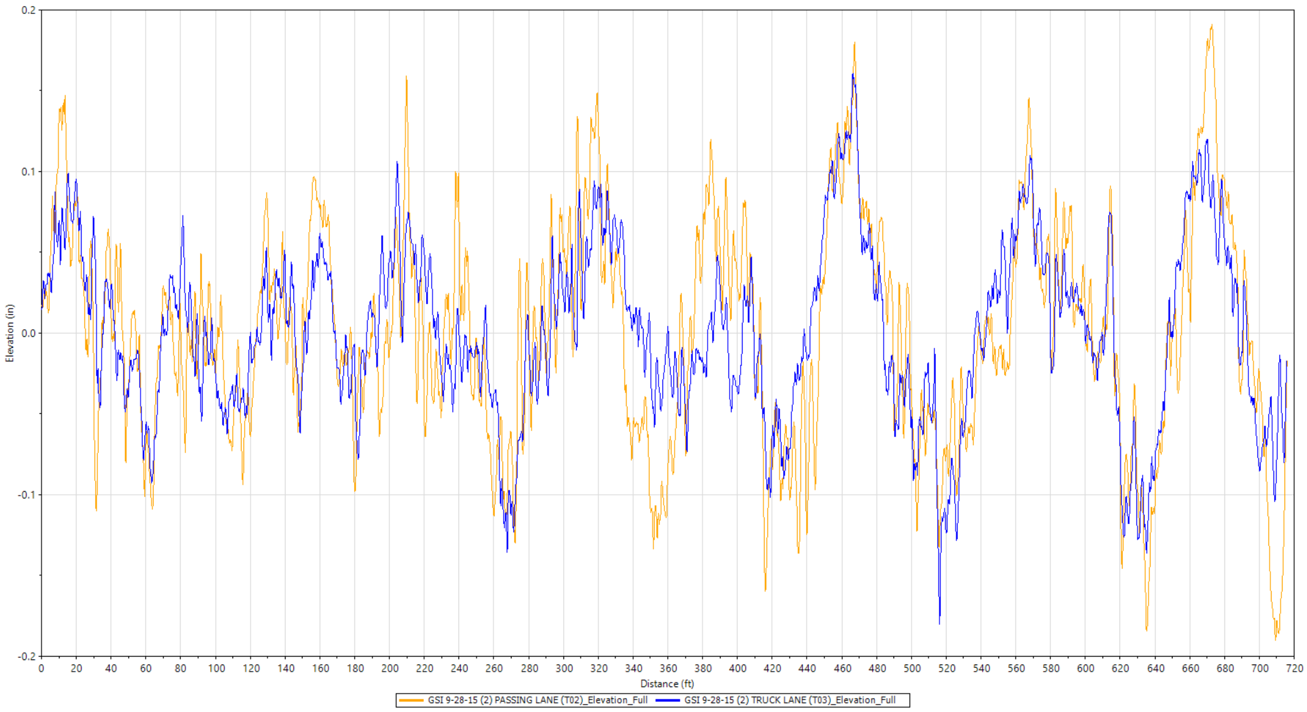

Figure 10. Profile deviations in the passing lane (yellow) are visibly greater than the truck lane (blue) on 28SEP2015.

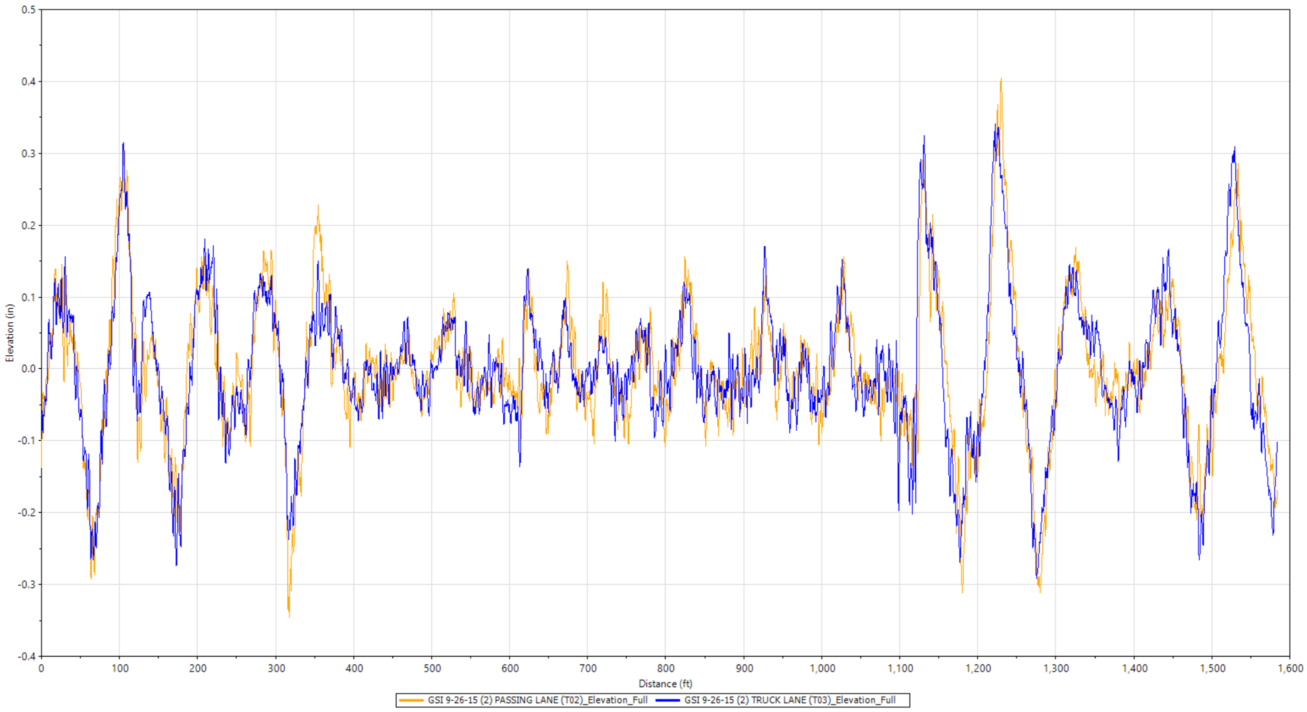

Figure 11. Profile deviations for the Passing Lane (yellow) and Truck Lane (blue) are more closely matched on 26SEP2015.

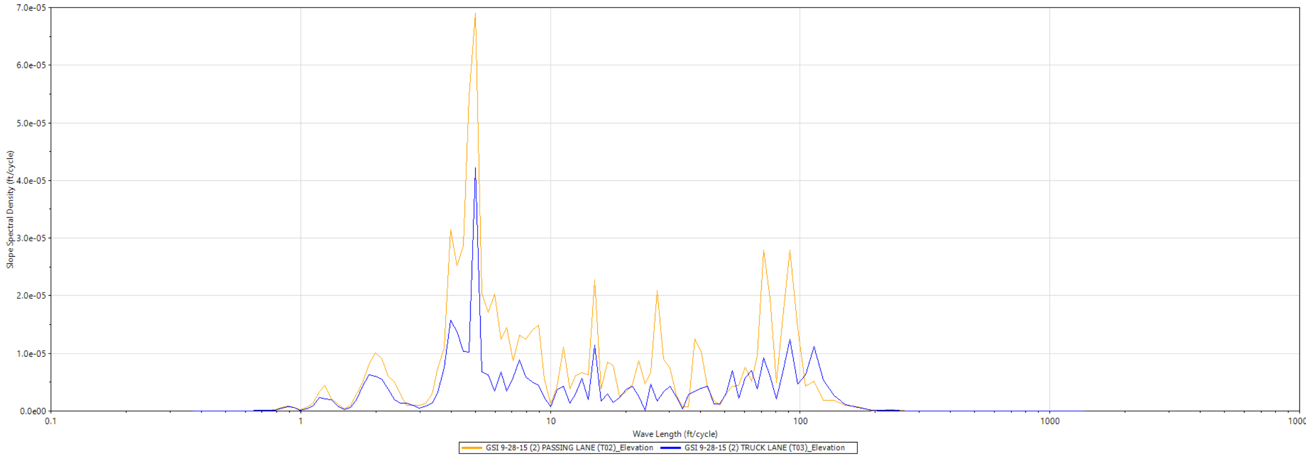

Figure 12. PSD for 28SEP2015 shows the differences in the contribution to roughness in the passing lane (yellow) than truck lane (blue) at the 4′, 5′, 15′, 27′, 70′ and 90′ wavelengths.

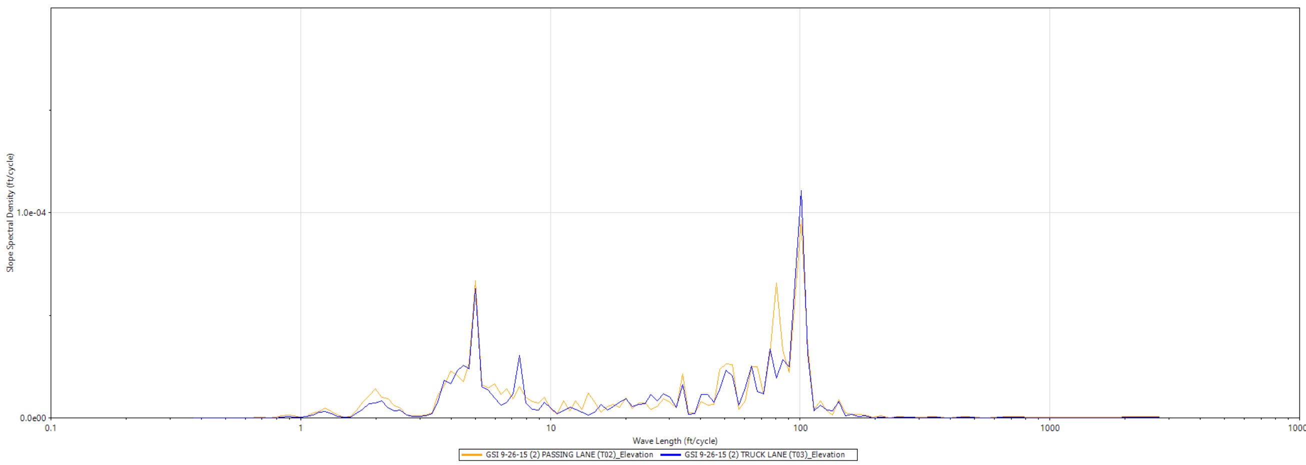

Figure 13. PSD for 26SEP2015 shows the contribution to roughness at various wavelengths is very similar for the passing lane and truck lane.

c. Based on the ProVAL analyses and the fact that there is significant daily variability in the hardened profiles, it appears that the difference in real-time IRI between the passing lane and truck lane is valid (i.e., the GSI is capturing actual profile deviation directly behind the paver). There are likely multiple factors contributing to the difference between the passing lane and truck lane real-time GSI profiles, including but not limited to the following:
    i. Equipment adjustments – vibrator frequency, vibrator height and head height.
    ii. 3D stringless system – sensitivity, model points and distance between the robotic laser and prism.
    iii. Measurement error (to a lesser degree than other factors) – vibration of the GSI in the passing lane.
    iv. Smoothness and cross-slope of the padlines – the paver tracks were out on the cement-treaded permeable subbse shoulders, which was significantly rougher than the asphalt separation layer. It’s possible that the outside shoulder padline (truck lane) was smoother than the inside shoulder padline (passing lane), although this was not verified. The cross-slope of the inside shoulder (passing

lane) also broke opposite (sloping away from) the main lanes, leaving the paver tracks on that shoulder bearing primarily on the inside edge of the track pads.

2) The real-time results in the passing lane were much more different than the hardened results in the passing lane than in the truck lane.
    a. Even though the IRI results between real-time and hardened profiles are different, the data shows that they parallel each other closely (Figure 14), indicating that the difference is not likely due to RTP measurement error.

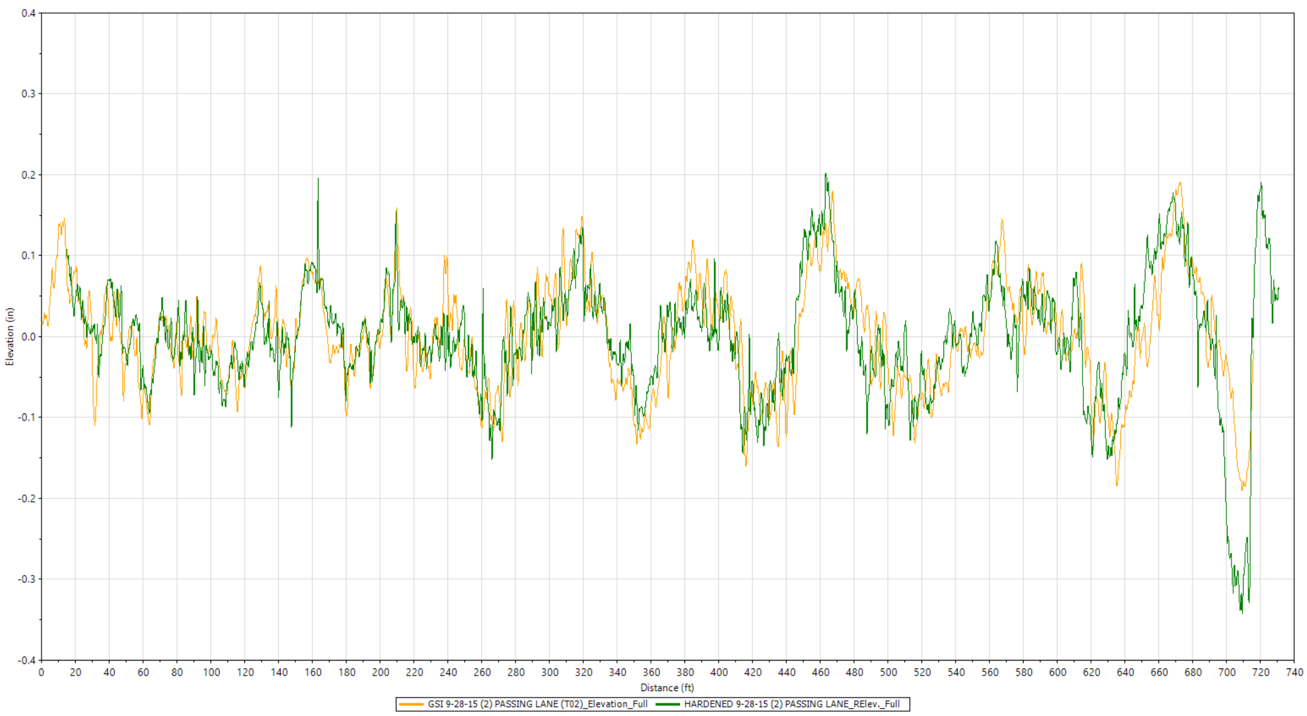

Figure 14. Comparison of Real-Time (yellow) and Hardened Profiles (green).

    b. Building upon the previous observations a PSD plot from 28SEP2015 (Figure 15) shows differences between the wavelengths contributing to roughness in the passing lane for the GSI real-time data and hardened data. The following observations can be made from this PSD analysis:
        i. Shorter wavelength roughness in the hardened profile is likely from macrotexture (burlap drag and tining) applied behind the GSI sensors.
        ii. Real-time roughness at the 5’ wavelength was significantly reduced by hand finishing.
        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.
        iv. The source of roughness present in the hardened profile at longer wavelengths needs additional investigation.

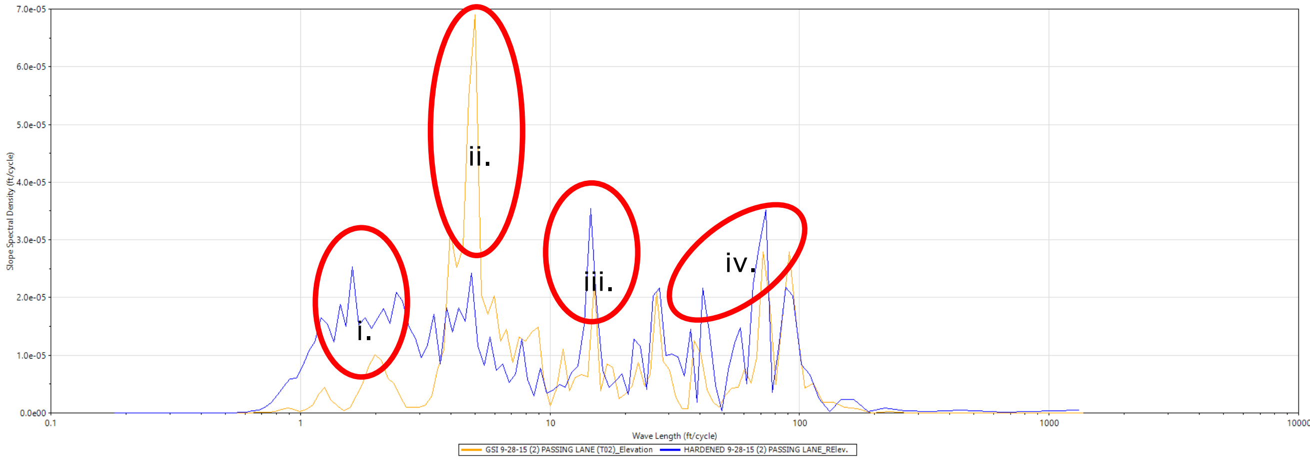

Figure 15. PSD plot showing contribution of different wavelengths to roughness for GSI (yellow) and hardened (blue) profile data for 28SEP2015.

Construction Artifacts

Paver Stops

The GSI was used to log paver stops. These events were transferred to ProVAL in an attempt to determine if paver stops were a contributing factor to localized roughness. Figure 16 shows a continuous IRI analysis from 25SEP2015 with a threshold value of 120 in/mi (red line) and a baselength of 25′. Event flags shown across the top of the graph indicate paver stops. No clear correlation can be made between paver stops and localized roughness from this analysis.

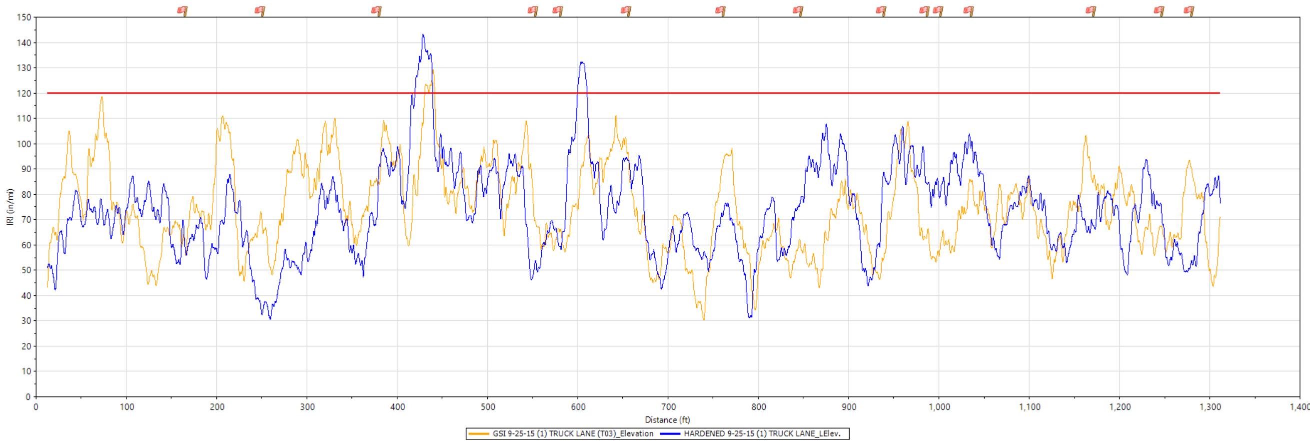

Figure 16. Localized roughness analysis (continuous IRI with 25′ baselength) showing paver stops as red flags along top of graph.(Note: GSI data in yellow, hardened profile data in blue.)

Superelevation Transitions

Superelevation transitions are typically more difficult to maintain smoothness through, because the head height is changing from one side of the paver to the other. The analysis shown in Figure 17 demonstrates this common trend. Localized roughness is generally lower in the areas of normal cross-slope.

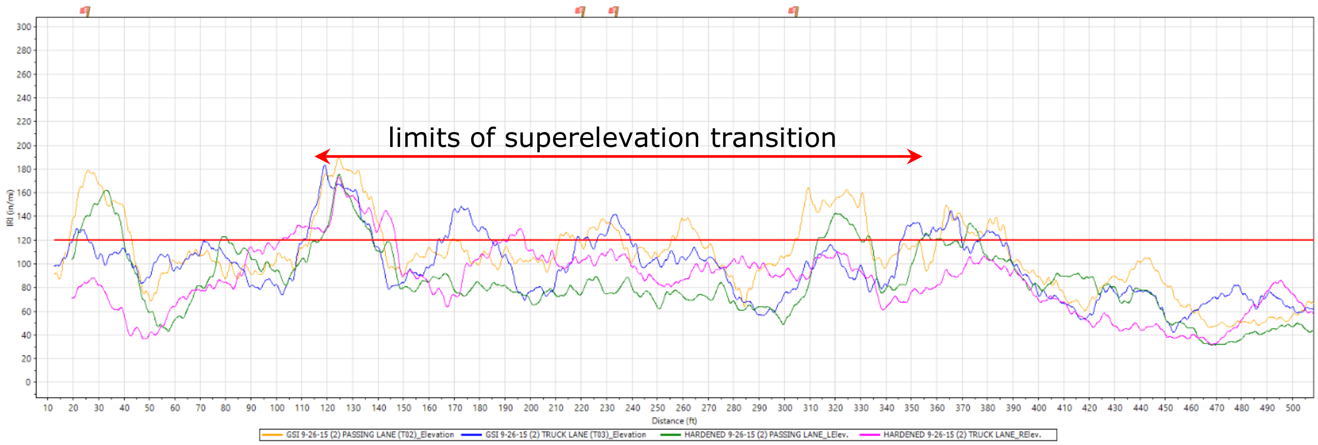

Figure 17. Localized roughness analysis (continuous IRI with 25' baselength) showing higher roughness through the superelevation transition.

Wet Concrete and Angle of Attack

Notes from the on-site observation indicated some wet loads of concrete and a concurrent adjustment to the paver's angle of attack (added lead/draft as shown in Figure 18) on 26SEP2015. Adding lead/draft to the paver generally helps to fill surface voids because more pressure is imparted to the surface. But, this increased pressure at the trailing edge of the pan makes the paver more sensitive to changes in the concrete workability and uniformity. The impact on localized roughness from these two factors can be seen in Figure 19 as the localized roughness increases where the wet loads were encountered, and then gradually decreases after the lead/draft is reduced.

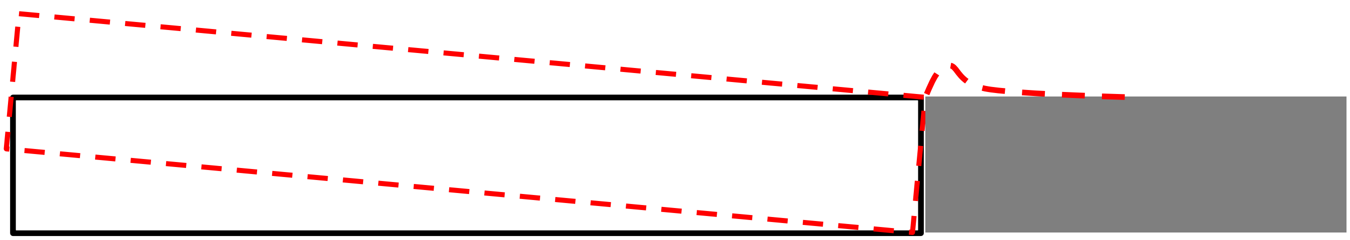

Figure 18. Illustration of adding lead/draft to the paver (dashed red lines indicate lead/draft added and "concrete boil" from added pressure at the back of the pan).

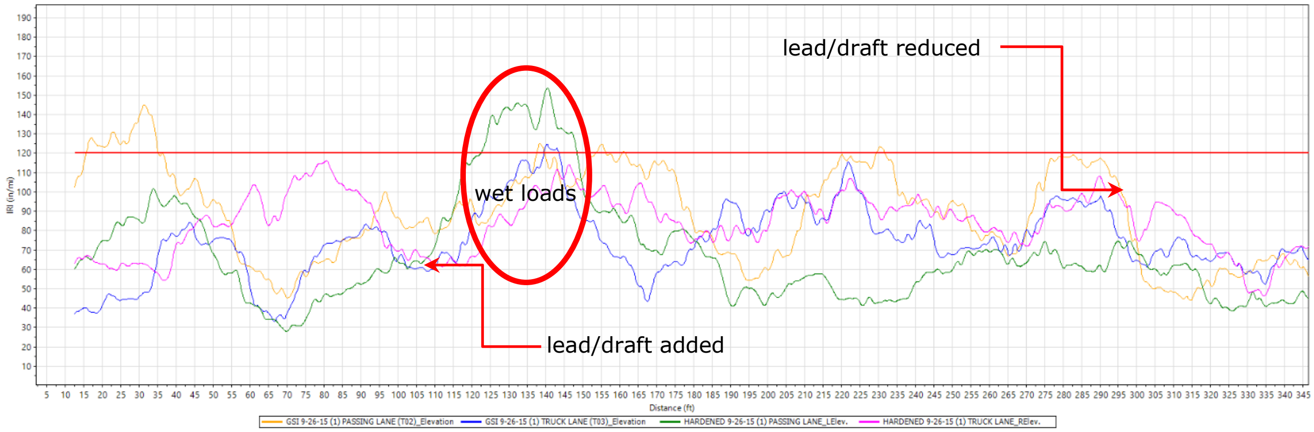

Figure 19. Localized roughness analysis (continuous IRI with 25' baselength) showing increased roughness from wet loads and added lead/draft followed by a decrease after a reduction in lead/draft (Note: GSI shown in yellow and blue, hardened shown in green and pink).

Dowel Basket Dislodged Ahead of the Paver

During paving on 26SEP2015, a dowel basket in the truck lane was dislodged by the paver. Although removed and replaced, this event caused a sizable bump and dip which resulted in localized roughness (Figure 20), and was not fully corrected with hand finishing.

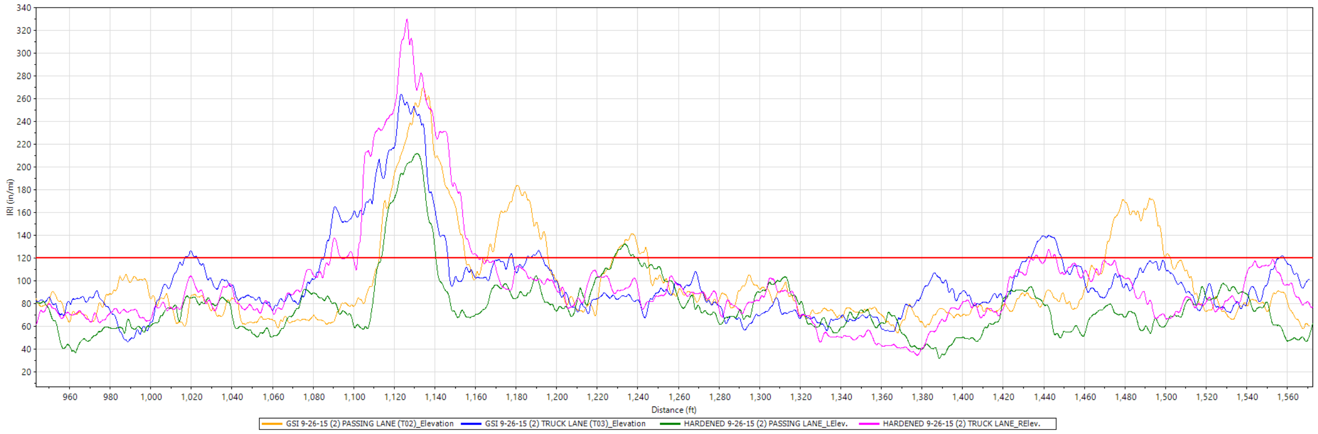

Figure 20. Localized roughness analysis (continuous IRI with 25′ baselength) showing an "event" caused by a dislodged dowel basket (Note: GSI shown in yellow and blue, hardened shown in green and pink).

CONCLUSIONS and LESSONS LEARNED

The following points summarize the preliminary conclusions made from profile analyses and on-site documentation as well lessons learned from the equipment loan.

Profile Analyses:

- Although there was variability between the real-time IRI values for the passing lane and truck lane, these differences could also be seen in hardened data and the real-time profiles parallel the hardened profiles.
- There are differences between the hardened and real-time IRI values, but these are primarily due to changes in the slab (e.g., hand finishing, texturing and slab curling/warping) between the time the real-time measurements are taken at the back of the paver and the hardened profiles are collected.
- Despite the differences between real-time and hardened IRI values, the GSI provides good QC feedback and reliable profile measurements.
- The preferred placement of real-time profiles is directly behind the paver where proper and timely adjustments can be made based on the real-time feedback.
- No clear correlation could be found between paver stops and localized roughness.
- Superelevation transitions did contribute to localized roughness.
- Large "events" such as a dislodged dowel basket contribute to localized roughness and are difficult to correct with hand finishing.