EL07-2016 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

FIELD REPORT: ILLINOIS EQUIPMENT LOAN

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

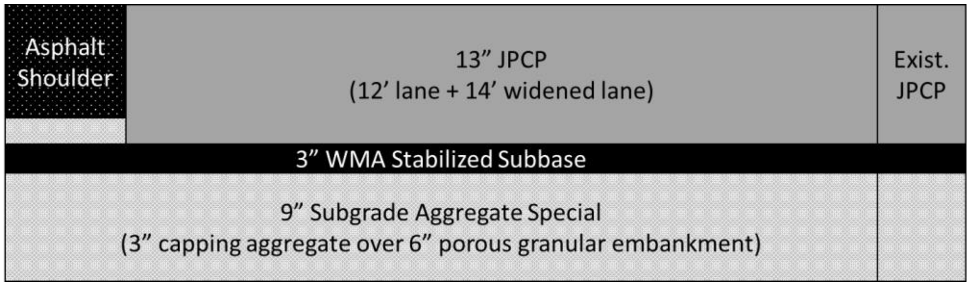
This report summarizes the activities and findings of the equipment loan conducted in Illinois for the Illinois Tollway Authority.

PROJECT DETAILS

The equipment loan was performed in June 2016 on a project near Chicago-O'Hare International Airport. Table 1 summarizes the pertinent project details.

Table 1. Chicago I-90 (Jane Addams Memorial Tollway) Project Information

Item	Details
Project Location	Mainline paving (widening into the median) in the eastbound and westbound lanes of I-90 between mileposts 73.3-76.6. Paving during the equipment loan was between the bridge over Higgins Creek and S. Mt. Prospect Rd. 

Item	Details
Route	I-90
Agency	Illinois Tollway Authority
Paving Contractor	K-Five Construction Corporation
Paving Equipment	Guntert & Zimmerman 850 paver with Dowel Bar Inserter (DBI), Leica stringless machine control
Real-Time System	Gomaco GSI
Typical Sections	13″ JPCP on 3″ WMA stabilized subbase over aggregate subgrade 
Joint Spacing	Transverse: matching joints of existing pavement (nominally 15′ c/c) Longitudinal: joint between 12′ lane and 14′ widened lane with No. 6 tie bars inserted by the paver
Gomaco GSI Setup	Paver width = 26′ Sensor #1: left edge of the paver (~3′ from edge of slab) Sensor #2: right edge of paver (adjacent to existing pavement, ~3′ from edge of slab)
Miscellaneous Details	DBI with oscillating correcting beam (OCB) was used. Finish pan behind OCB and burlap drag behind the finishing pan (burlap was in front of RTPs). Hand finishing consisted of a 20′ straightedge and 12′ float. Final surface texture consisted of a turf drag followed by longitudinal tining. This was a Performance Related Specification project. Dowel bar alignment was checked with a MIT Scan and thickness was measured with a MIT Scan T2. Smoothness requirements (0.1 mile lots) were a maximum MRI of 80 in/mi with a standard deviation of 10 in/mi.

IMPLEMENTATION ACTIVITIES

On-site coordination with the contractor began on June 15, 2016 with installation of the Gomaco GSI and calibration dry runs on June 16 and 17, 2016. Collection of real-time profile data began on June 20, 2016 and concluded on June 27, 2016, providing four days of data collection (after rain delays, etc.). The contractor set up and operated the real-time system themselves on the last day of paving (June 27). Although there was additional paving beyond these dates, there were additional delays associated with moving the paver around a bridge and the GSI was needed for another scheduled equipment loan.

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
15JUNE2016	Contractor coordination and preparation for install.
16JUNE2016	GSI Installation10:30 am to 4:30 pm.
17JUNE2016	GSI calibration.
20JUNE2016	Real-time profile data collection on WB lanes, 7:00 am to 3:30 pm from approximately 3903+38 to 3890+04.
21JUNE2016	No work. Contractor verifying dowel bar alignment with MIT Scan
22JUNE2016	No work due to rain.
23JUNE2016	Real-time profile data collection on WB lanes, 7:35 am to 2:05 pm from approximately 3890+07 to 3874+49. Paver turned around to begin paving EB lanes.
24JUNE2016	Real-time profile data collection on EB lanes, 6:15 am to 12:55 pm from approximately 3874+82 to 3889+25.
27JUNE2016	Real-time profile data collection by the contractor, from approximately 3892+30 to 3904+40.

OBSERVATIONS, DATA and ANALYSES

Paving operations were observed to be quality conscious and efficient, although material delivery was sometimes delayed by traffic on I-90 during peak travel times. This project represented the first equipment loan on a paver using a DBI, so the project team anticipated seeing some differences in RTS profile features normally associated with dowel baskets.

Figures 1 through 8 illustrate the installation of the GSI and different aspects of the paving equipment and processes used by K-Five.

Figure 1. Gomaco GSI behind finish pan and burlap.

Figure 2. Concrete delivery to the paver.

Figure 3. Concrete distribution in front of the paver.

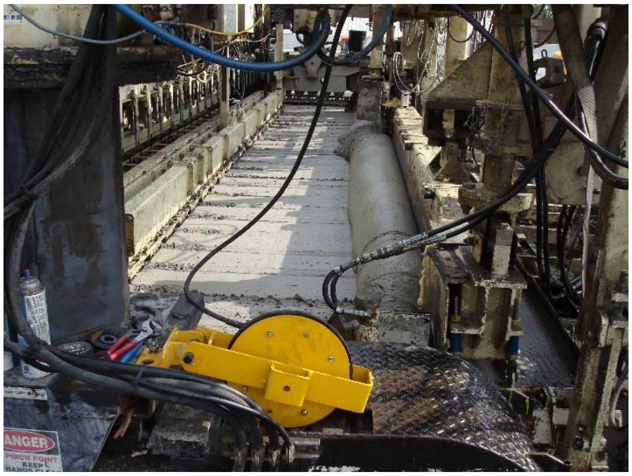


Figure 4. Concrete roll in front of DBI oscillating correcting beam.

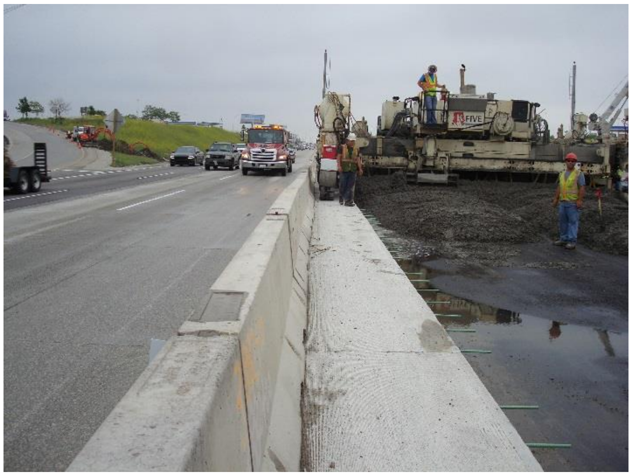


Figure 5. Constrained paving conditions on the companion paving side.

Figure 6. Stable padline on the non-companion paving side.

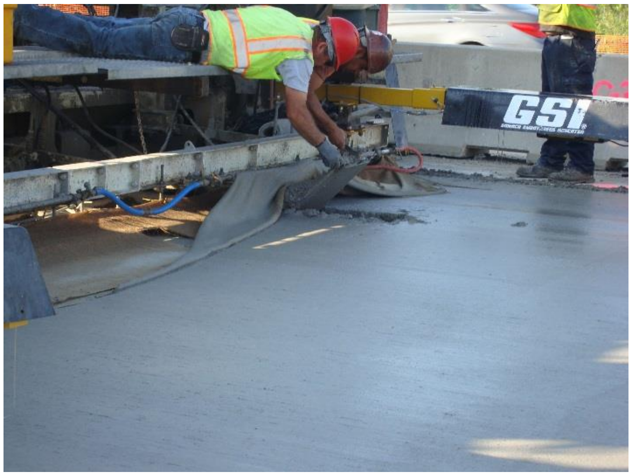


Figure 7. Repair to DBI on Day 3 of paving near the right GSI sensor.

Figure 8. Typical Hand Finishing Behind the Paver

CONCRETE MIXTURE

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

Table 3. I-90 Tollway Concrete Mixture Proportions

SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

REAL-TIME SMOOTHNESS IMPLEMENTATION

Mix Design & Proect Info.

General Information

Project:	I-90 ILLINOIS TOLL ROAD
Contractor:	K-FIVE
Mix Description:	MAINLINE
Mix ID:	TL-01-3S
Date(s) of Placement:	n/a

Cementitious Materials	Source	Type	Spec. Gravity	lb/yd³	% Replacement by Mass
Portland Cement:	ILLINOIS, LASALLE	I	n/a	315	
GGBFS:	SKYWAY, S. CHICAGO	100	n/a	106	20.11%
Fly Ash:	FLY ASH DIRECT, DALLMAN	F	n/a	106	20.11%
Silica Fume:					
Other Pozzolan:					
				527	**lb/yd³**
				5.6	**sacks/yd³**

Aggregate Information	Source	Type	Spec. Gravity SSD	Absorption (%)	% Passing #4
Coarse Aggregate #1:	VULCAN, OPT, BARTLETT	n/a	n/a	n/a	n/a
Intermediate Aggregate:	VULCAN, SYCAMORE	n/a	n/a	n/a	n/a
Fine Aggregate #1:	CONSOLIDATED,MARENGO	n/a	n/a	n/a	n/a
Fine Aggregate #2:					

Coarse Aggregate %:	n/a
Intermediate Aggregate %:	n/a
Fine Aggregate #1 % of Total Fine Agg.:	n/a
Fine Aggregate #2 % of Total Fine Agg.:	n/a
Fine Aggregate #1 %:	n/a
Fine Aggregate #2 %:	n/a

Mix Proportion Calculations

Water/Cementitious Materials Ratio:	0.414
Air Content:	6.50%

	Volume (ft3)	Batch Weights SSD (lb/yd3)	Spec. Gravity	Absolute Volume (%)
Portland Cement:	n/a	315	n/a	n/a
GGBFS:	n/a	106	n/a	n/a
Fly Ash:	n/a	106	n/a	n/a
Silica Fume:	n/a	n/a	n/a	n/a
Other Pozzolan:	n/a	n/a	n/a	n/a
Coarse Aggregate #1:	n/a	1,632	n/a	n/a
Intermediate Aggregate:	n/a	412	n/a	n/a
Fine Aggregate #1:	n/a	1,172	n/a	n/a
Fine Aggregate #2:	n/a	n/a	n/a	n/a
Water:	n/a	218	n/a	n/a
Air:	n/a	n/a	n/a	n/a
		3961		
	Unit Weight (lb/ft³)	**146.7**		

Admixture Information	Source/Description	oz/yd3	oz/cwt
Air Entraining Admix.:	GRT SA-50	9.24	1.75
Admix. #1:	GRT 400 NC (WRA TYPE A)	21.10	4.00
Admix. #2:	GRT R (RETARDER TYPE D)	18.45	3.50
Admix. #3:			

Combined gradation data is provided in Table 4 and Figures 9 and 10.

Table 4. QC Sieve Analysis Data

SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

REAL-TIME SMOOTHNESS IMPLEMENTATION

Combined Gradation Test Data

Project: I-90 ILLINOIS TOLL ROAD
Mix ID: TL-01-3S
Sample Comments: MIX DESIGN FROM K-FIVE
Test Date: SINGLE POINT QC DATA FROM K-FIVE

Total Cementitious Material: 527 lb/yd^3

Agg. Ratios: 50.80% 12.80% 36.40% 100.00%

Sieve	Coarse #1	Intermediate	Fine #1	Fine #2	Combined % Retained	Combined % Retained On Each Sieve	Combined % Passing
2 ½"	100%	100%	100%		0%	0%	100%
2"	100%	100%	100%		0%	0%	100%
1 ½"	100%	100%	100%		0%	0%	100%
1"	100%	100%	100%		0%	0%	100%
¾"	95%	100%	100%		3%	3%	97%
½"	58%	100%	100%		21%	19%	79%
⅜"	32%	97%	100%		35%	14%	65%
#4	8%	31%	100%		56%	21%	44%
#8	1%	6%	87%		67%	11%	33%
#16	1%	2%	70%		74%	7%	26%
#30	1%	1%	55%		79%	6%	21%
#50	1%	1%	26%		90%	11%	10%
#100	0.4%	1%	4%		98%	8%	2%
#200	0.1%	0.1%	1.6%		99.4%	1.1%	0.6%

Workability Factor: **32.0** 24% Coarse Sand

Coarseness Factor: **52.1** 26% Fine Sand

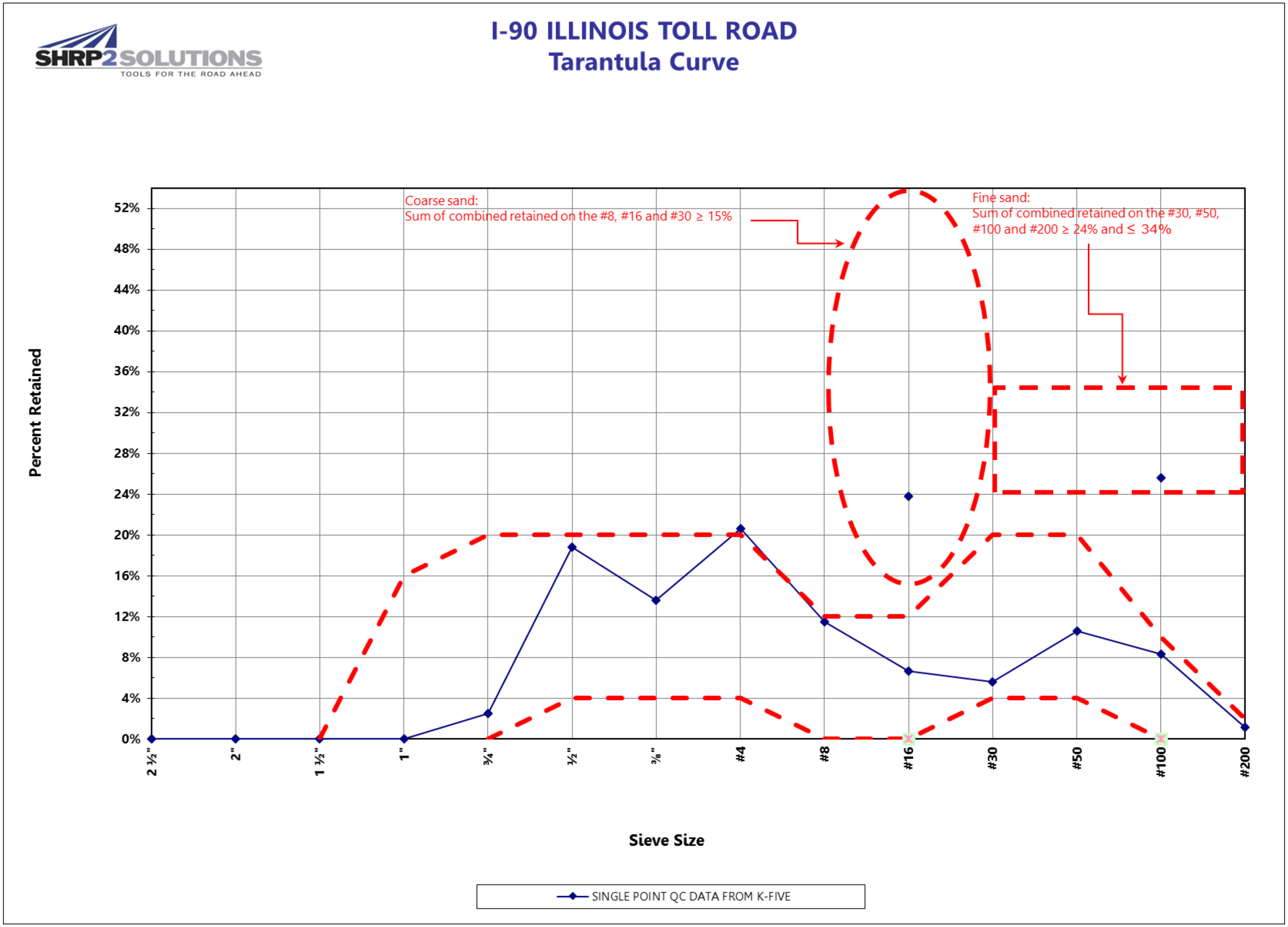


Figure 9. I-90 Combined Percent Retained (Tarantula Curve)

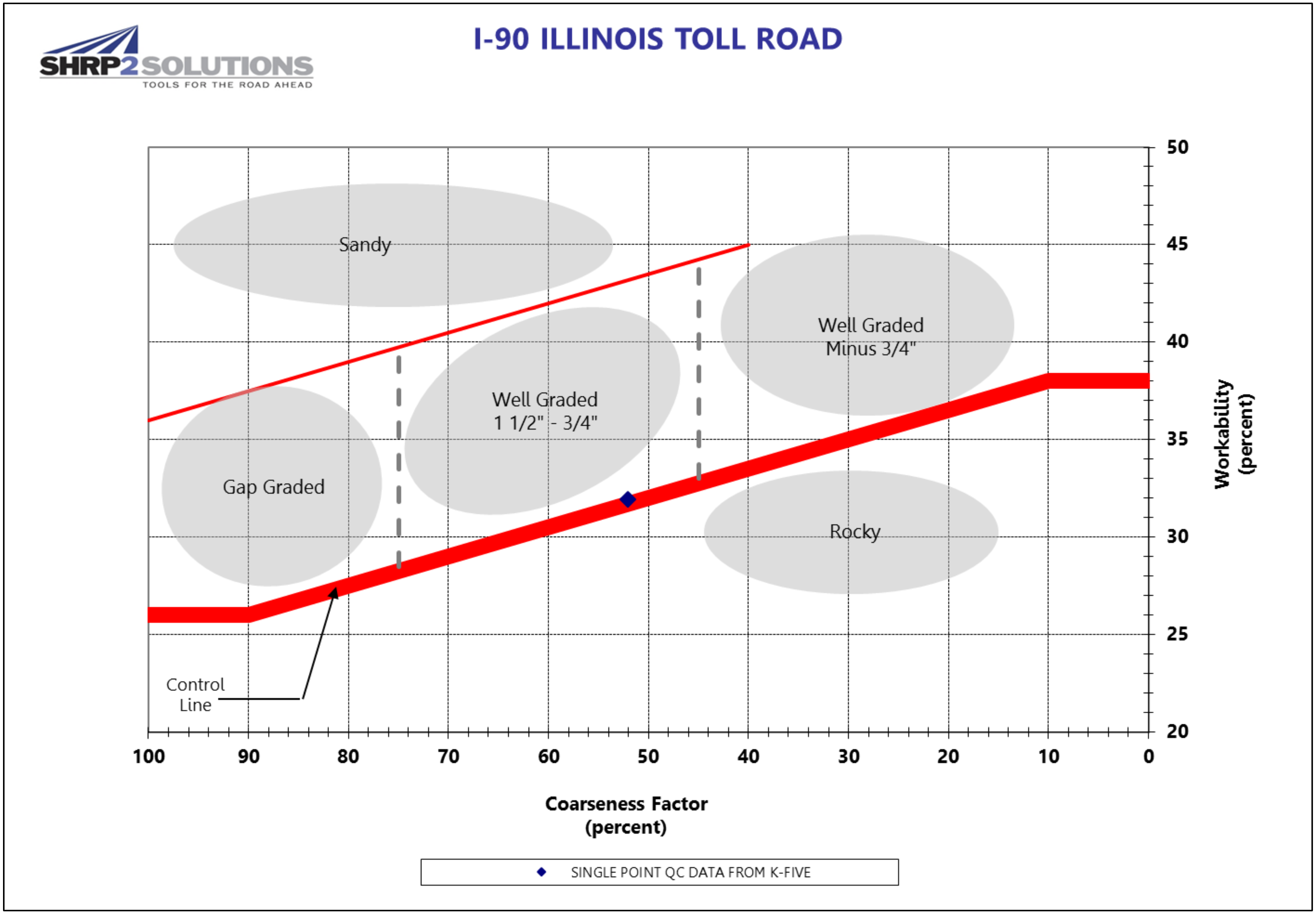


Figure 10. I-90 Combined Gradation Coarseness and Workability Factors

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. For the I-90 equipment loan, hardened profile data were collected by the Illinois Tollway Authority on July 5, 2016, approximately 1-2 weeks after paving of these sections. It is important to note that paving during the four days of the equipment loan was under very similar conditions. All paving was on the same base and subbase, there were no superelevation transitions, pavement thickness or width transitions, leave-outs, or other characteristics. Paving was on essentially a tangent section with very little change in elevation.

Real-Time Smoothness (RTS) vs. Hardened Profile

A tabular comparison of hardened and real-time smoothness results is shown in Table 5. Note that hardened Lane 1 profile data corresponds to the left side of the paver (GSI Sensor 1) and hardened Lane 2 profile data corresponds to the right side of the paver (GSI Sensor 2). More specifically, hardened Lane 1 left wheelpath (LWP) corresponds most closely to GSI Sensor 1 and hardened Lane 2 right wheelpath (RWP) corresponds most closely to GSI Sensor 2. FHWA's ProVAL software was used to align the RTS and hardened QC profiles and compute IRI values for each.

Table 5. Summary of Overall IRI Results

	Real-Time GSI IRI (in/mi)		Hardened IRI (in/mi)		Length (ft)
Date	Sensor 1 (Left Side)	Sensor 2 (Right Side)	Lane 1, LWP (Left Side)	Lane 2, RWP (Right Side)	
Day 1, File 1 (6/20/16, WB)	134.1	178.3	84.4	85.9	320
Day 1, File 2 (6/20/16, WB)	154.2	165.5	85.1	85.9	986
Day 2 (6/23/16, WB)	108.2	117.7	70.3	64.6	1,558
Day 3 (6/24/16, EB)	104.7	123.6	65.7	75.7	1,443
Day 4 (6/27/16, EB)	114.2	140.1	87.8	110.8	1,210
Weighted Average	**118.3**	**136.2**	**76.4**	**82.7**	**5,517**

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

1) As shown in Table 5, hardened results were anywhere from 26-92 in/mi (21-52 percent) lower than the real-time numbers, with an overall average of 35-40 percent lower. While this is not unexpected, the difference (which is fairly consistent during the four days of paving) is higher than what has been observed during previous equipment loans.
2) With the exception of hardened data for Day 2, the right side (paver tracks on existing pavement) was consistently rougher than the left side (paver tracks on subgrade) in both the RTS and hardened profile.
   a. The difference in roughness between the left and right side was also consistently greater in the RTS data than the difference between left and right side for the hardened data, with a couple of exceptions.
   b. This could potentially be attributable to roughness in the existing pavement that was reflected into the new pavement. In this case, because the hardened data did not show as much of a disparity between the left and right side, finishing processes may have helped remove most of those effects.
3) Figures 11 and 12 show how the RTS and hardened profile data follow similar trends, but also how certain features (spikes) in the RTS data do not show up in the hardened data, likely because they were removed by finishing processes.

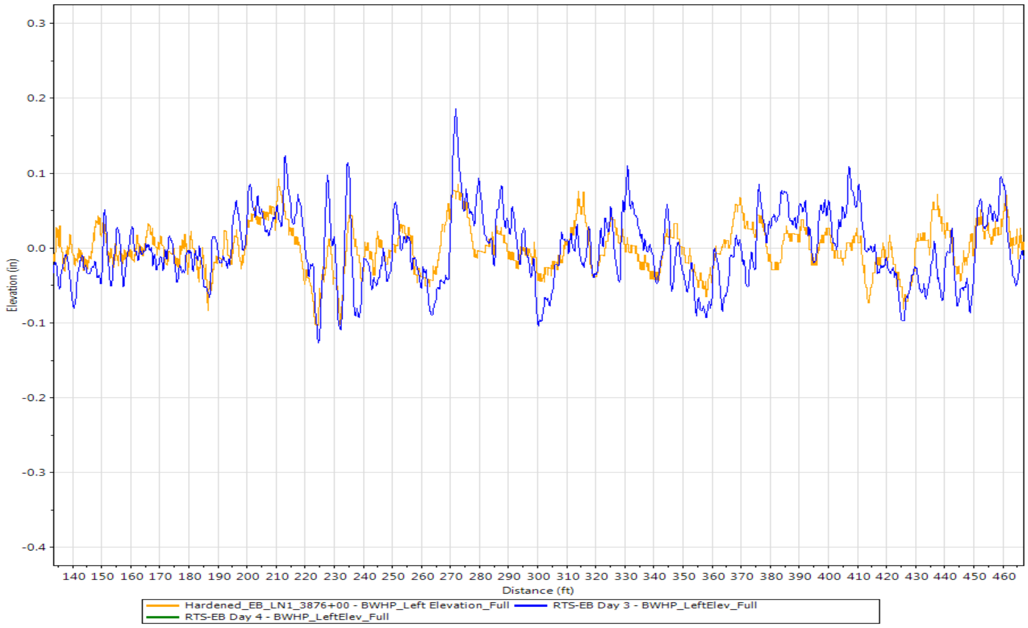


Figure 11. Typical hardened (yellow) and RTS (blue) profile data for EB Lane 1.

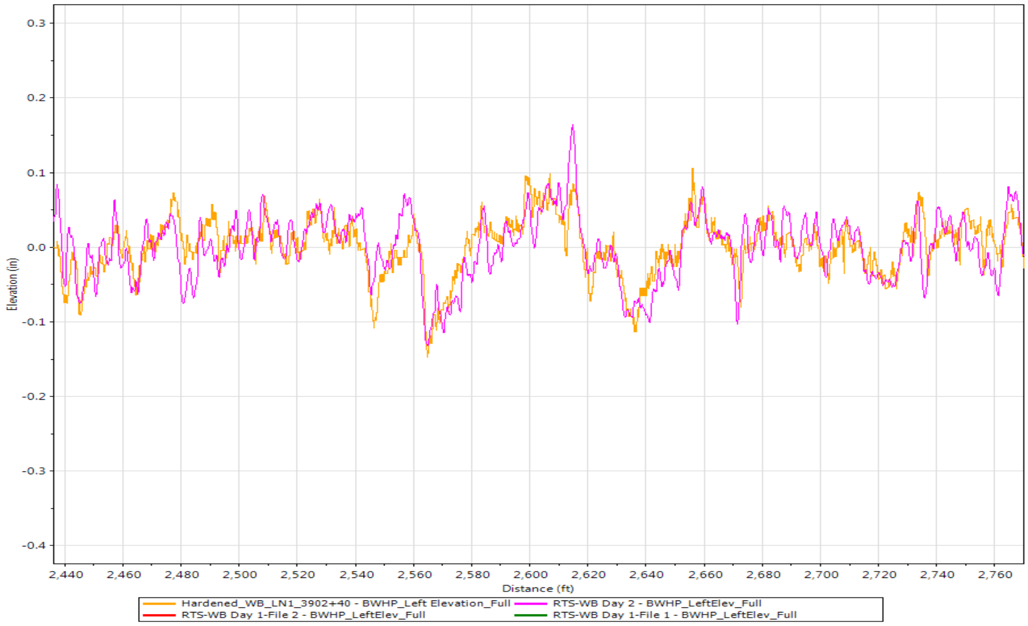


Figure 12. Typical hardened (yellow) and RTS (magenta) profile data for WB Lane 1.

4) Figures 13 and 14 show the short continuous IRI (localized roughness) for the RTS and hardened profile data. Similar to the profile data, the IRI follows similar trends, but the hardened data is noticeably smoother than the RTS data. This, again, is likely due to the finishing processes which removed much of the short-wavelength profile features.

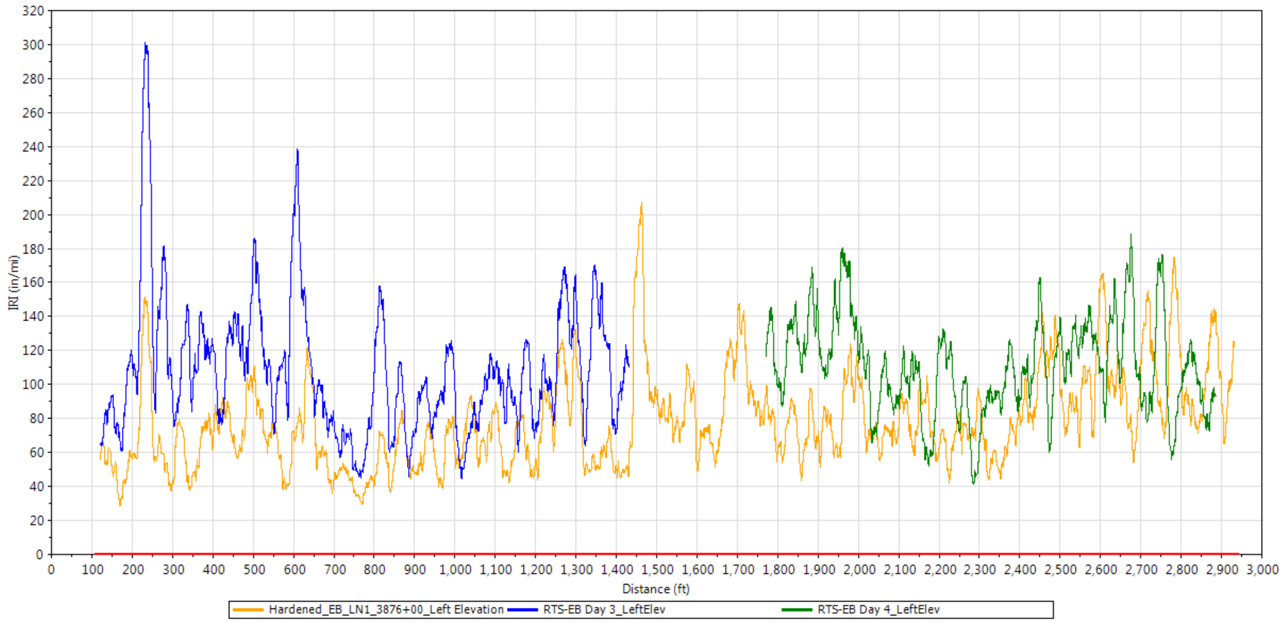


Figure 13. Hardened (yellow) and RTS (blue/green) short baselength (25 ft) continuous IRI for EB Lane 1.

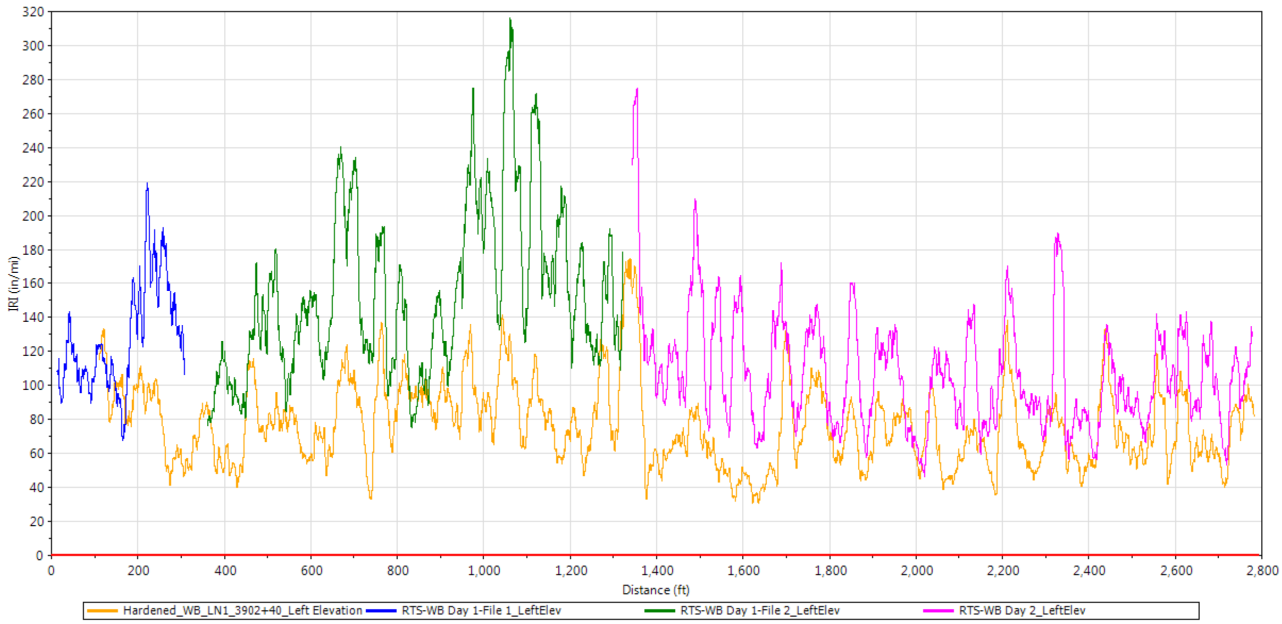


Figure 14. Hardened (yellow) and RTS (blue/green/magenta) short baselength (25 ft) continuous IRI for WB Lane 1.

5) Figures 15 and 16 show the results of the ProVAL Power Spectral Density (PSD) analysis of the RTS and hardened profile data (note that the data was high-pass filtered at 100 ft to better view content most relevant to ride quality). The dominant content in the RTS data is primarily shorter wavelength, less than 10 ft and primarily in the 4-5 ft range. For the hardened data, the shorter wavelength content is still apparent but much less dominant than it was in the RTS data. This would tend to confirm the idea that much of the shorter wavelength roughness picked up in the RTS profiles is significantly reduced by finishing operations. The cause of the dominant content in the 4-5 ft range in the RTS profiles is not readily apparent.

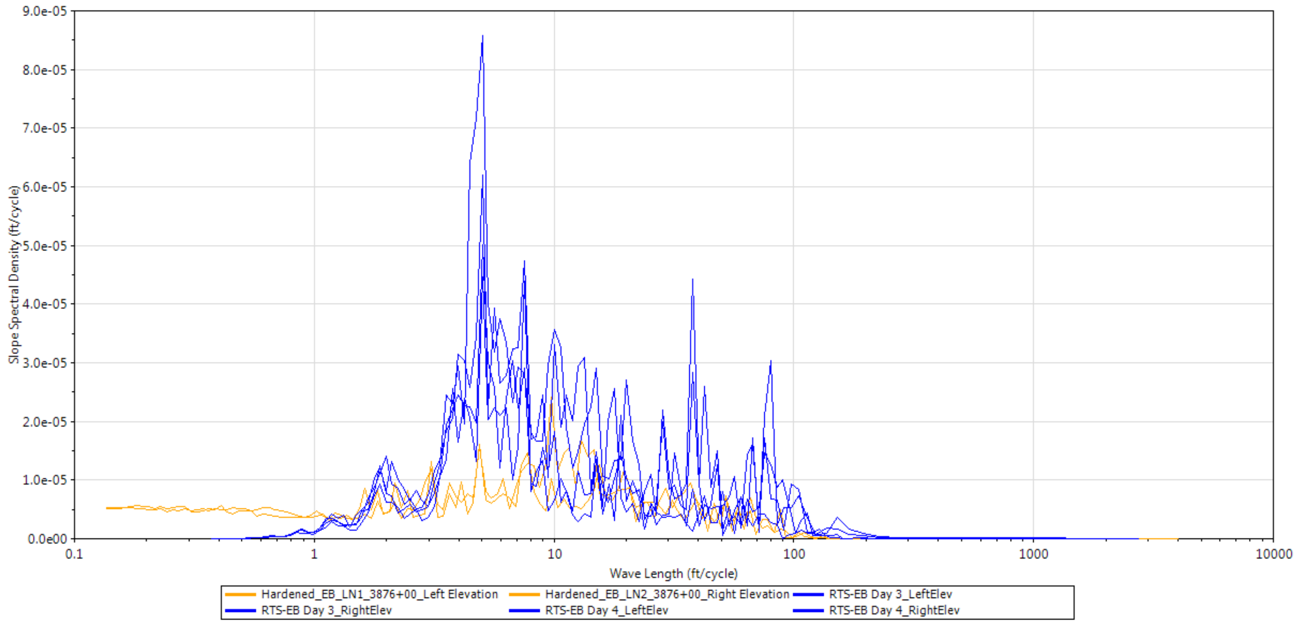


Figure 15. PSD plot for EB lanes showing hardened (yellow) and RTS (blue) wavelength content.

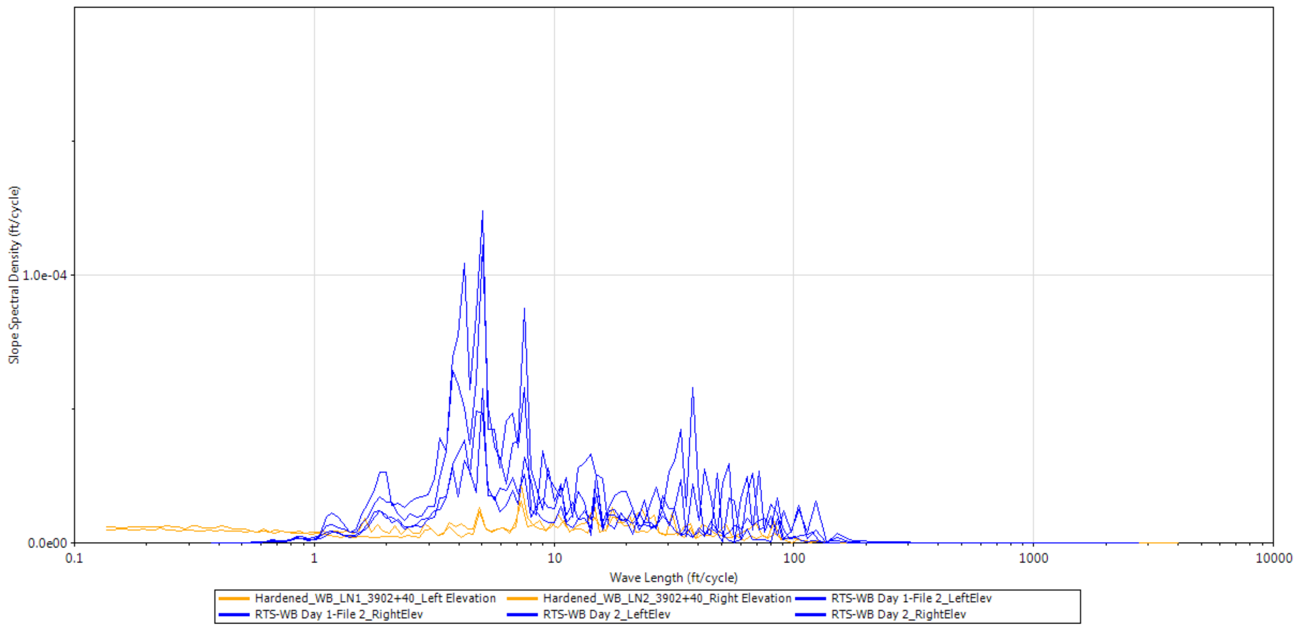


Figure 16. PSD plot for WB lanes showing hardened (yellow) and RTS (blue) wavelength content.

Construction Artifacts

Joint Effects

RTS profiles for projects with dowel baskets generally show very pronounced effects of dowel baskets on the pavement profile. There is generally dominant PSD content at the joint spacing wavelength (and at associated harmonic wavelengths) in the RTS data, and to a lesser extent, in the hardened data as well. These effects are likely attributed to either dowel basket rebound or additional consolidation of the concrete around the dowel bars, leaving slightly high or low areas in the profile at the dowel baskets, and may or may not be reduced by finishing processes. This equipment loan revealed that use of a DBI in lieu of baskets can reduce this effect. Figures 15 and 16, above, show the PSD plots for the EB and WB lanes, respectively. Although there is content at the 15 ft joint spacing wavelength, it is not the dominant content, particularly for the RTS profiles.

Localized Roughness from DBI Malfunction

Approximately 220 ft into paving on Day 3, a malfunction if the DBI left a steel plate in the pavement which required the paver to stop in order for the plate to be removed and the area to be backfilled and hand finished. Figure 17 shows the effects of this artifact on the pavement profile in both the RTS and hardened data. Finishing processes were able to remove much of the effect of this artifact. Figure 18 shows the effect on roughness and how the effect is nearly undetectable in the hardened profile.

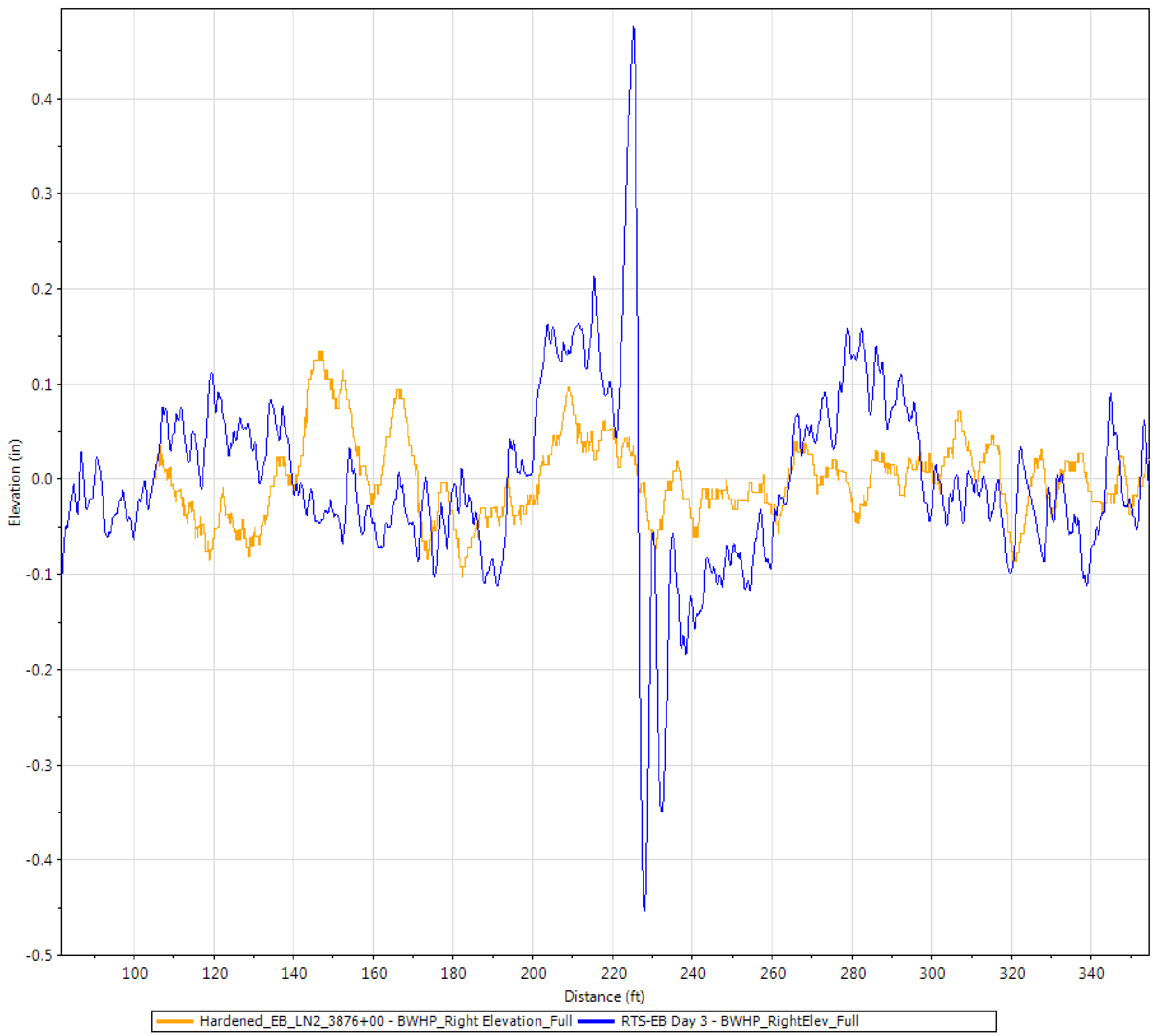


Figure 17. Effect of the DBI malfunction is apparent in the RTS profile (blue) but not as much in the hardened profile (yellow).

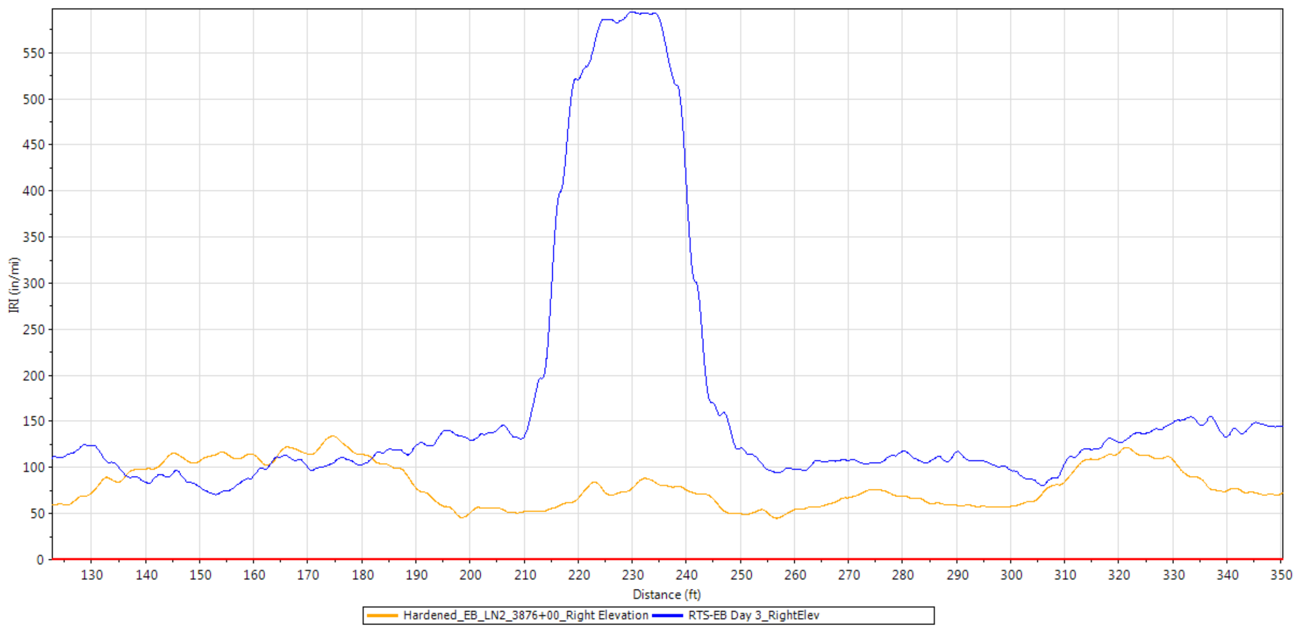


Figure 18. Effect of DBI malfunction on localized roughness apparent in the RTS profile (blue) but not in the hardened profile (yellow).

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:

- RTS and hardened profile data synchronized well for the four days of paving for the equipment loan. Both showed similar trends in profile elevation and roughness, with the RTS profiles showing more shorter-wavelength content and higher roughness than the hardened profiles.
- A PSD analysis of the profile data showed shorter wavelength content to be dominant, confirming that this content was likely the cause of the higher roughness than the hardened profiles as finishing processes removed much of the shorter wavelength content.
- The lack of dominant content at the joint spacing wavelength in both the RTS and hardened profile data indicates that the use of DBI can potentially reduce the effects of joint-related roughness caused by dowel baskets.
- The RTS profiler showed the effects of localized roughness events on IRI and the improvement achieved through finishing processes. As such, RTS profilers are a valuable tool for QC feedback during paving.