Improving Rideability at a Newly Constructed Pavement-Bridge Interface
A Case Study

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ABSTRACT: Ride quality is a key factor in the long term performance of our highways and bridges. Improved smoothness results in increased longevity and lower annual maintenance costs in addition to greater comfort and safety for the traveling public. This paper examines the rideability of a newly resurfaced bridge deck and the associated tie-in with the existing pavement on a construction project in Ohio which was subjectively deemed “too rough” to remain as is. It discusses the selection of diamond grinding as the chosen corrective action, the use of the diamond grinding simulation found within the FHWA’s ProVAL software to develop a grinding strategy, and an objective assessment of ride quality based on the International Roughness Index (IRI) before and after grinding.

1 INTRODUCTION

1.1 *Background*

This paper highlights some of the events that took place on Ohio Department of Transportation (ODOT) construction project 614-05 on US Route 23 in southern Ohio during the 2006/2007 construction season. The majority of the project consisted of resurfacing the four lane highway by removing 25 mm (1 inch) of the old asphalt surface and paving an additional 90 mm (3.5 inches) of asphalt in 2 lifts on the full depth asphalt pavement. The pavement resurfacing project adjoined a 264 m (865 foot) long, five-span continuous concrete slab bridge. The structure had its approach slabs and parapets replaced in addition to a 70 mm (2.75 inch) micro silica overlay after 25 mm (1 inch) of the existing deck was removed. The project was awarded to a prime contractor (Prime) who specializes in asphalt paving. The work on the bridge was done by a subcontractor (Sub) who specializes in such Portland cement concrete construction. Completion of the asphalt resurfacing up to the newly decked bridge occurred in the autumn of 2006 at the end of the construction season.

1.2 *Problem*

Personnel from ODOT’s Office of Pavement Engineering collected road profiles on the project with one of ODOT’s high speed non-contact inertial profilers in order to perform a quality assurance review of the contractor’s supplied smoothness data on the pavement. Road profiles are different from the general profile found in construction plans in that they are a series of discrete relative elevations along each wheel path of the roadway (Sayers & Karamihas, September 1998). In this case, the relative elevations were collected at 25 mm (1 inch) intervals longitudinally. Road profiles were collected on the entire length of the project including the bridge. Although the Prime earned a bonus for pavement smoothness on the project, there were ride issues with the pavement coming into the bridge. The rideability at the pavement-bridge interface, particularly the northbound lanes at the south end of the structure, indicated a need for improvement. Digital forward looking images were taken while road profiles were collected. Figure 1 shows the asphalt surface is high coming into the bridge. Also noticeable in the photo is an oil spot on the deck in the center of the outside lane. This is indicative of a roughness event upstream which causes vehicles to lose oil from their engines/undercarriage due to the induced vibration, dropping it on the highway surface.

Figure 1. Approaching bridge northbound right lane.

ODOT has been using ProVAL software since it was first released in 2001. ProVAL (Profile Viewing and AnaLysis) is an engineering software application that allows users to view and analyze pavement profiles in many different ways. ProVAL is a product developed by The Transtec Group through a contract with the US Federal Highway Administration (FHWA) and the Long Term Pavement Performance Program (LTPP). Using ProVAL 2.72 software, the road profiles were analyzed using the rolling straightedge simulation. Results showed that the approach slabs and the deck were in violation of the 3.2 mm in 3 m (1/8 inch in 10 feet) rolling straightedge requirement outlined in ODOT Specification 451.12 - Surface Smoothness (State of Ohio, Department of Transportation, January 2005). This was consistent with visual observations of the entry approach slab of the right northbound lane where water would pond during and after a rain. Numerous smoothness violations occurred in the left wheel path of both outside lanes. Figure 2 shows the straightedge violations of the left wheel path of the right hand northbound lane on the bridge. Figure 3 shows the straightedge violations of the right wheel path of the same lane on the bridge. Note the large deviation spikes near 32 m, 91 m, 151 m, 210 m, and 268 m (105 ft, 300 ft, 495 ft, 690 ft, and 880 ft) are locations of sliding plate expansion joints. Nearly the entire right wheel path was constructed within smoothness specifications if you exempt the expansion joint locations.

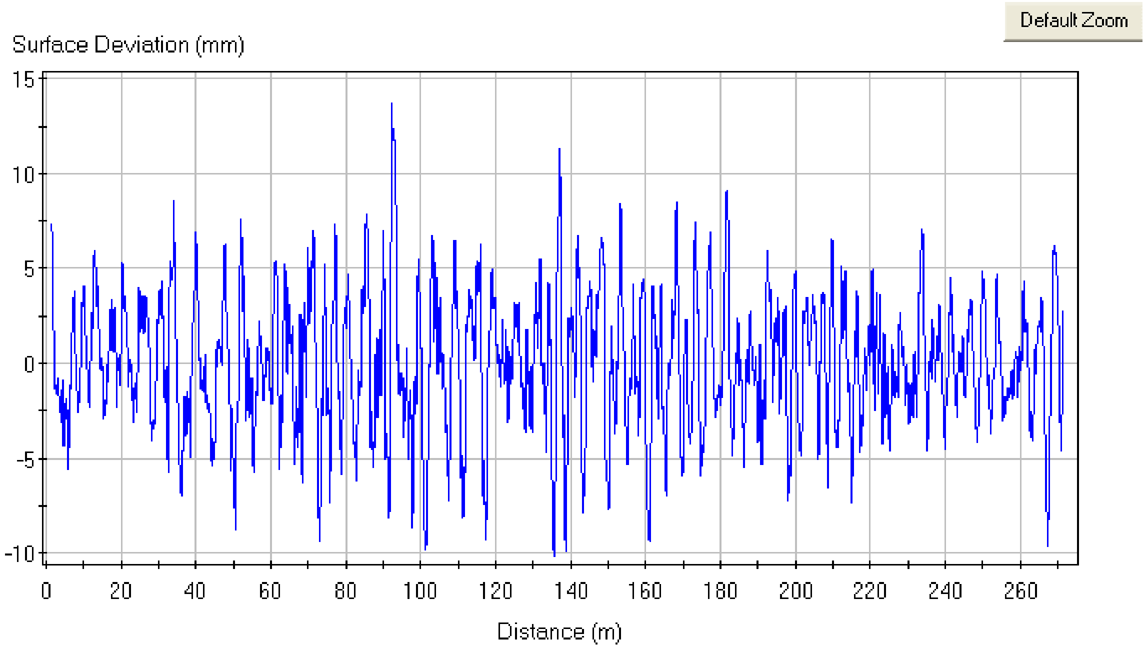


Figure 2. Rolling straightedge analysis, left wheel path of right northbound lane.

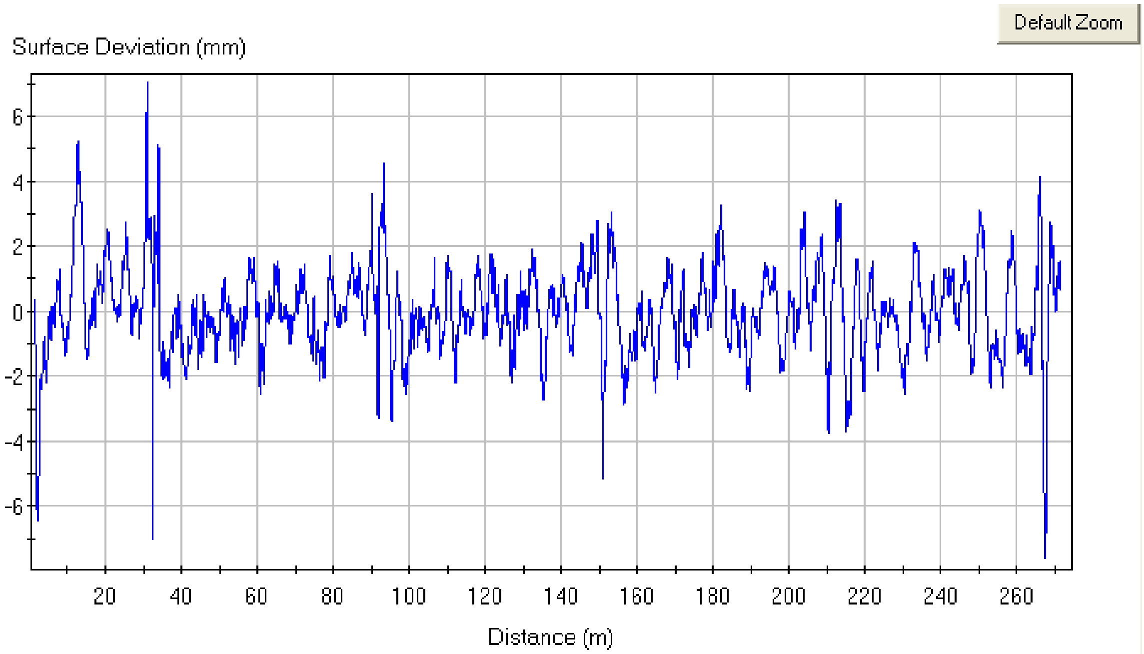


Figure 3. Rolling straightedge analysis, right wheel path of right northbound lane.

The bridge deck was placed in phases that resulted in construction joints being located in the left wheel path of both outside lanes. This caused the outside lanes to ride rougher than the inside lanes by comparison. Figure 4 shows one of the construction joints on the bridge deck.

Figure 4. Construction joint in left wheel path of right lane.

The International Roughness Index (IRI) was the rideability (smoothness/roughness) metric used on this project to objectively evaluate the ride quality at the bridge encounter. IRI is an algorithm based on a generic vehicle suspension system. The IRI simulates suspension movement as the generic suspension model travels over the input road profile(s) at a simulation speed of 80 km per hour (50 miles per hour). The units are vertical accumulated distance of suspension stroke (between the axle and body of the vehicle) per longitudinal distance of travel (Gillespie, 1992). Units are often reported as meters per kilometer (or inches per mile). Thus, lower values of IRI are smoother riding while higher values are rougher riding. The FHWA has determined ranges of IRI that fit particular categories (very good to very poor) of road roughness on our highways. Those ranges are as follows: Very Good - IRI below 0.95 m/km (60 in/mile), Good – IRI up to 1.50 m/km (95 in/mile), Fair – IRI up to 2.68 m/km (170 in/mile), Poor – IRI up to 3.47 m/km (220 in/mile), and Very Poor – IRI exceeding 3.47 m/km (220 in/mile) (FHWA, 2004). The IRI data for each wheel path of the four lanes is shown in Figure 5.

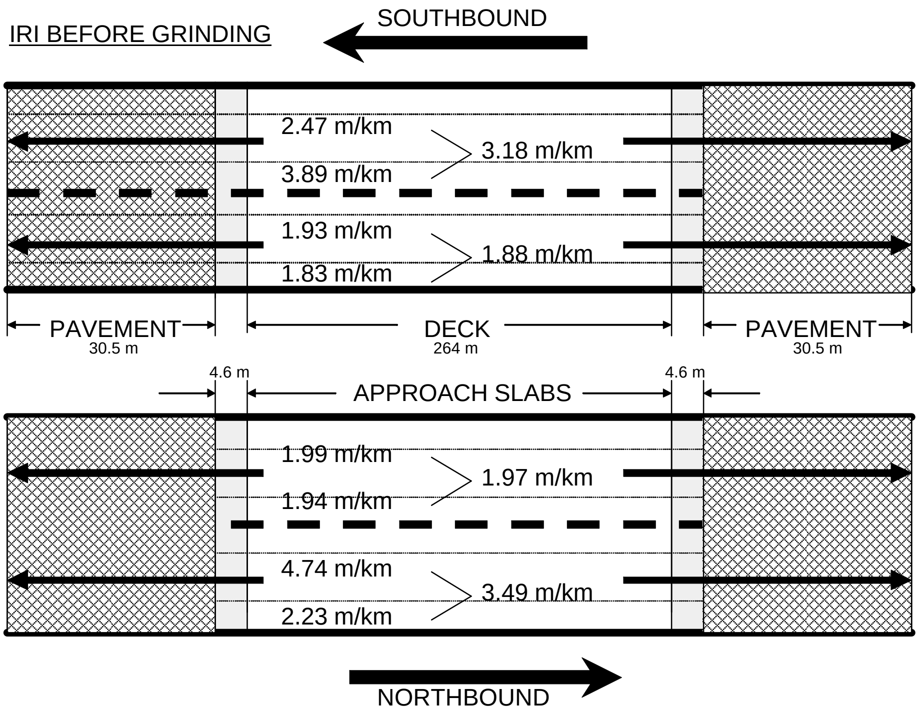


Figure 5. IRI data for each wheel path and lane before grinding.

1.3 *Potential solutions*

ODOT's Area Engineer for the project called a meeting between ODOT, the Prime, and the Sub. It was decided at the meeting not to debate the alleged design, construction or inspection causes of the undesirable rideability but rather to focus on available solutions. All three parties accepted responsibility and agreed to partner to arrive at an effective solution. Four courses of action were suggested. Each potential course of action is outlined more fully as follows:

?? Take no action, leave as is – As stewards of the project, it was agreed that this was not an option. From an engineering perspective it was clear that the increased maintenance cost and reduced longevity due to the increased dynamic loading caused by the roughness eliminated this course of action from the available options. From a customer service perspective, it would be unacceptable to allow the traveling public to be subjected to such a poor level of ride quality at the conclusion of the construction project.

?? Mill and repave asphalt pavement adjoining the bridge approaches – The Prime suggested this course of action stating they could mill the pavement adjoining the bridge approaches until a desirable ride was achieved. Once the desired elevation was achieved, they would then mill an additional 38 mm (1 ½ inches) of depth across the area and replace the material with another 38 mm (1 ½ inch) surface course. This solution had merit but only addressed the roughness caused by the pavement coming into the bridge. It did nothing to improve the roughness associated with the approach slab or the deck. Further, the milling would be an iterative process and would require subjective opinion of where and how deep to mill and when the ride was improved enough to perform the subsequent milling and repaving. This process could be time consuming and was not guaranteed to deliver an improvement in ride quality.

?? Construct asphalt overlay across bridge approaches and deck – Although this course of action could dramatically improve ride quality, it was considered impractical. It was quickly dismissed as it was deemed the most expensive of all the alternatives, the most time consuming and disruptive to traffic, and it presented a whole host of other engineering issues and problems to address.

?? Diamond grinding – This was the solution of choice for several reasons. It was the only systematic solution that addressed smoothness holistically for the pavement, approach slabs and deck. Grinding could occur anywhere on the surface with exception to steel sliding plate expansion joints. This solution had a predictable outcome verified by the FHWA ProVAL software utilizing the built in diamond grinding simulator (Swan & Karahimas, 2003). Grinding simulations were run on the collected profiles to demonstrate how much benefit (in terms of IRI improvement) could be expected by grinding a particular area utilizing one or two passes of the diamond grinder. Figure 6 shows the before and after continuous (Sayers, 1990) short, 7.6 m (25 ft), and long, 61 m (200 ft), base length calculation of IRI as well as the profile of the left wheel path north bound right lane of the deck and approach slabs as determined by ProVAL using the diamond grinding simulation with one pass of a grinding machine.

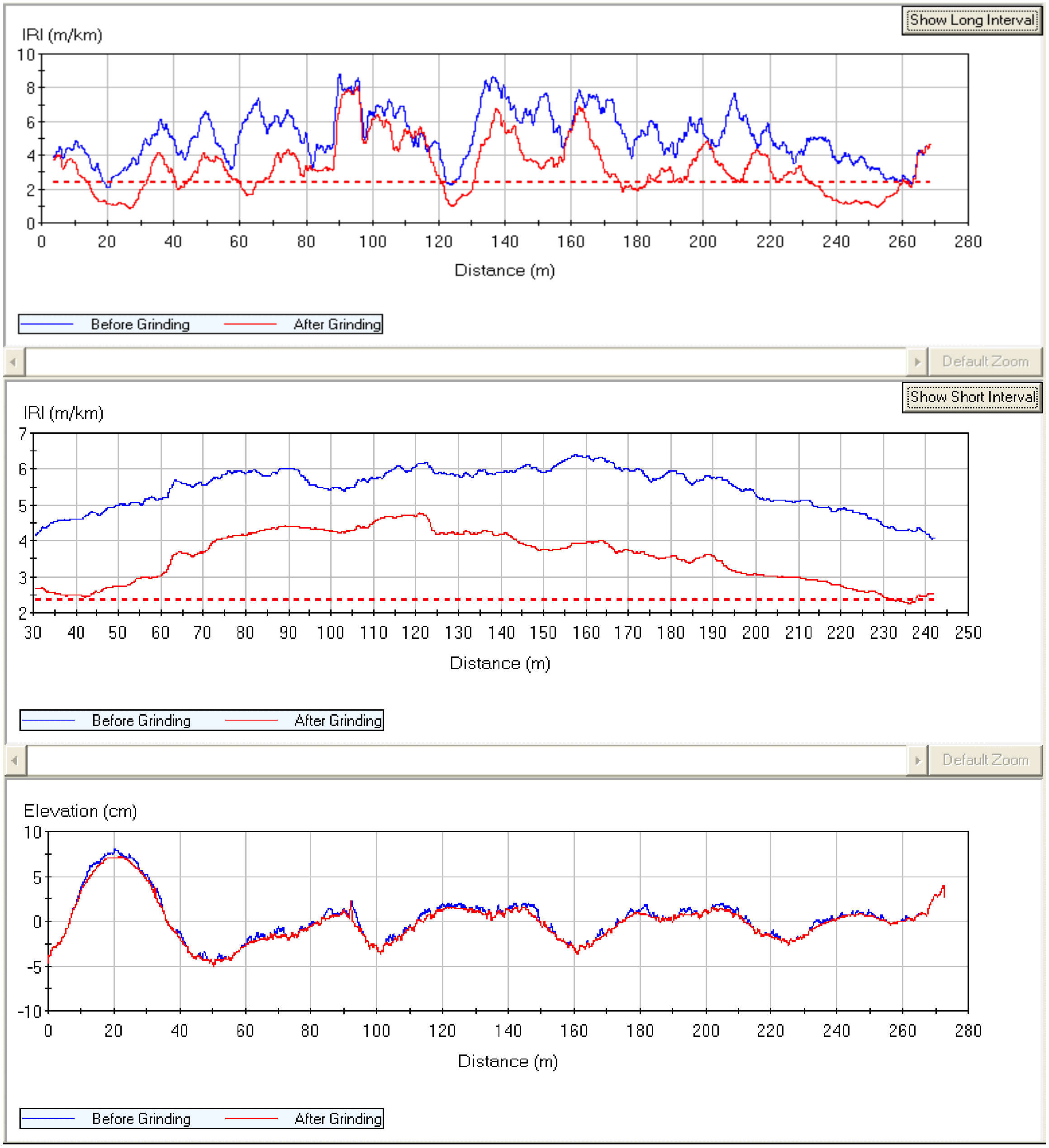


Figure 6. Grinding simulation of left wheel path (deck and approaches only) on northbound right lane, short/ long base length IRI, and road profile.

The diamond grinding solution was capable of completion in one day with minimal impact to traffic and at relatively low cost in comparison to the other alternatives. ODOT, the Prime and the Sub agreed to split the costs of the grinding three ways deciding this solution had the best cost-benefit ratio and a high probability of success.

2 DEVELOPMENT OF THE GRINDING STRATEGY

Once diamond grinding became the solution of choice, ODOT was tasked with developing the grinding strategy. This made sense since ODOT personnel had the most experience with the ProVAL software and in the end, ODOT has final responsibility as the owners of the facility. It should be noted that the ProVAL diamond grinding simulation is relatively new to the industry and prior to this project had never been utilized by ODOT on an actual project.

There are two weaknesses to the diamond grinding simulation in ProVAL that should be considered when developing a grinding strategy. First, the simulation has no feature to account for tapering in and out of the sections. This means that the termini points of grinding in the simulation may not agree well with results of actual grinding. Second, the road profiles which the grinding simulation uses as input and the simulation itself are only two dimensional. The X axis represents horizontal longitudinal distance along the surface while the Y axis represents elevation differences in the surface. The simulation does not account for the Z axis or transverse variation in the surface across the width of the lane. Obviously, diamond grinding equipment is three dimensional. Further, the grinding head may be set parallel to the plane of the machine or it can be set with one side higher or lower than the other making it askew with the plane of the machine. Lack of the third dimension in the simulation can contribute to differences in simulated versus actual grinding results.

Great effort was taken on this project to minimize the shortcomings of the simulation. This was done by soliciting the input of the diamond grinding company in the development of the grinding strategy. The experience and expertise of the grinding crew balanced the theory of the simulation with practicality. Clear communication between ODOT and the grinding contractor was critical to the success of the operation

After running multiple grinding scenarios in ProVAL, the most predicted improvement in ride-ability, evaluated by reduction of IRI were as follows and became the targeted areas:

?? Northbound lane south end of bridge reverse then forward double grind.

?? Northbound left wheel path of right lane (construction joint) - forward grind only.

?? Southbound left wheel path of right lane (construction joint) - forward grind only.

Grinding from pavement to approach slabs or approach slabs to pavement on all other lanes and ends of the bridge predicted only marginal reduction in IRI.

The following is a list of factors that further restricted grinding:

?? Five steel sliding plate expansion joints located transversely in the surface of the deck.

?? Raised pavement markers and painted lane lines on the pavement and the bridge deck must be maintained and left untouched.

?? Traffic control restrictions require one lane of traffic open in each direction.

?? One day of grinding forcing completion within eight hours.

Based on ProVAL's grinding simulation, the experience of the grinding crew, the restrictions placed on grinding, and engineering judgment, the following was the prioritized grinding strategy:

?? Northbound right lane – Diamond grind full lane width in the opposite direction of travel from 19 m (62 feet) of bridge deck across the 4.6 m (15 feet) entry approach slab ending with 61 m (200 feet) of pavement preceeding the bridge.. The same section was then diamond ground in the direction of travel full lane width including an additional 9 m (30 feet) of the deck ending at the first expansion joint.

?? Northbound right lane – Diamond grind left wheel path (one half lane width) in the direction of travel along the entire length of the bridge deck to correct longitudinal construction joint roughness. Grinding the bridge deck required the contractor to taper into and out of the deck segments to avoid contact with the steel expansion joints.

- ?? Northbound right lane – Diamond grind full lane width in the direction of travel from the approach slab/pavement interface away from the bridge approximately 19 m (62 feet) into the asphalt pavement section (opposite end of the bridge from the first section mentioned above).
- ?? Southbound right lane - Diamond grind left wheel path (one half lane width) in the direction of travel along the entire length of the bridge deck to correct longitudinal construction joint roughness. Grinding the bridge deck required the contractor to taper into and out of the deck segments to avoid contact with the steel expansion joints.
- ?? Southbound right lane - Diamond grind full lane width in the direction of travel from the approach slab/pavement interface away from the bridge approximately 19 m (62 feet) into the asphalt pavement section.

2.1 *Execution of grinding plan*

The project benefited from a clear day that facilitated completion of the entire grinding plan. Few alterations were made to the plan mid stream. To improve efficiency, the grinder operator ground all northbound forward passes in the left half of the lane in continuous passes. Likewise, all southbound grinding operations were completed in continuous passes.

3 RESULTS

Analysis of road profiles collected before and after diamond grinding allowed comparison of predicted improvement from ProVAL's grinding simulation with actual improvement. Results of the three targeted areas are summarized in Table 1.

Table 1. Before, predicted, and after IRI data for sections.

	IRI (m/km)				
	SECTION 1			SECTION 2	SECTION 3
	LWP	RWP	AVERAGE	LWP	LWP
BEFORE GRIND	2.39	2.41	2.40	5.12	4.06
PREDICTED (ProVAL)	1.72	1.67	1.70	3.28	2.75
AFTER GRIND	0.97	1.23	1.10	2.02	1.88
PREDICTED REDUCTION	0.67	0.74	0.71	1.84	1.31
ACTUAL REDUCTION	1.42	1.18	1.30	3.10	2.18

In all three of the targeted areas, the predicted improvement was exceeded. There are two possible reasons for this. The first is that ProVAL's default value for grinding head depth is zero. This means that the bottom of the head is in line with the bottom of the wheels of the machine, as if all were resting on the same plane. The default value for head height was used in all simulations. There was no way to validate the head depth of the grinder when it was used as there is no gauge and no easy way to reference the head height. It is likely that the grinding head was actually operated at a height deeper than the default value of zero. Further research would be required to validate this hypothesis. Another possible reason is that the simulation only used one pass in the left wheel paths of the two outside lanes over the longitudinal construction joint in the bridge deck. The grinder did not make one pass 1 m (3 feet) wide (width of the grinding head) in the center of the wheel path. Instead, the grinder made two passes, one tapering in laterally from the center lane line and another overlapping somewhat and tapering out laterally to the center of the lane. This in effect was more like a double forward grind than a single forward grind over the left wheel paths. It is worth noting that grinding the left wheel path did not correct all rolling straightedge violations. See Figure 7 for such analysis after grinding.

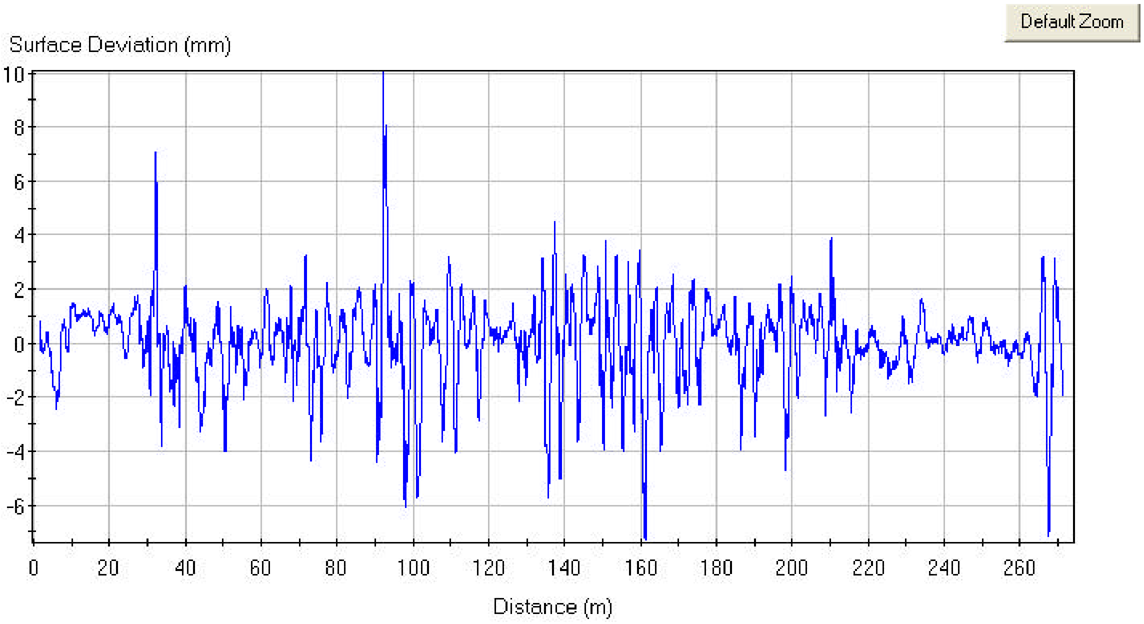


Figure 7. Rolling straightedge results after grinding left wheel path of the northbound right lane.

Grinding did cause an increase in roughness in one localized area. This increase in roughness was not predicted in the simulation. The continuous short base length IRI analysis reveals this moderate increase at the beginning of the pavement section which was ground leading into the bridge at the northbound right lane. It is suspected that this increase in localized roughness was due to the simulation's inability to taper in and out at grinding section termini points. Figure 8 illustrates this non-predicted increase in roughness.

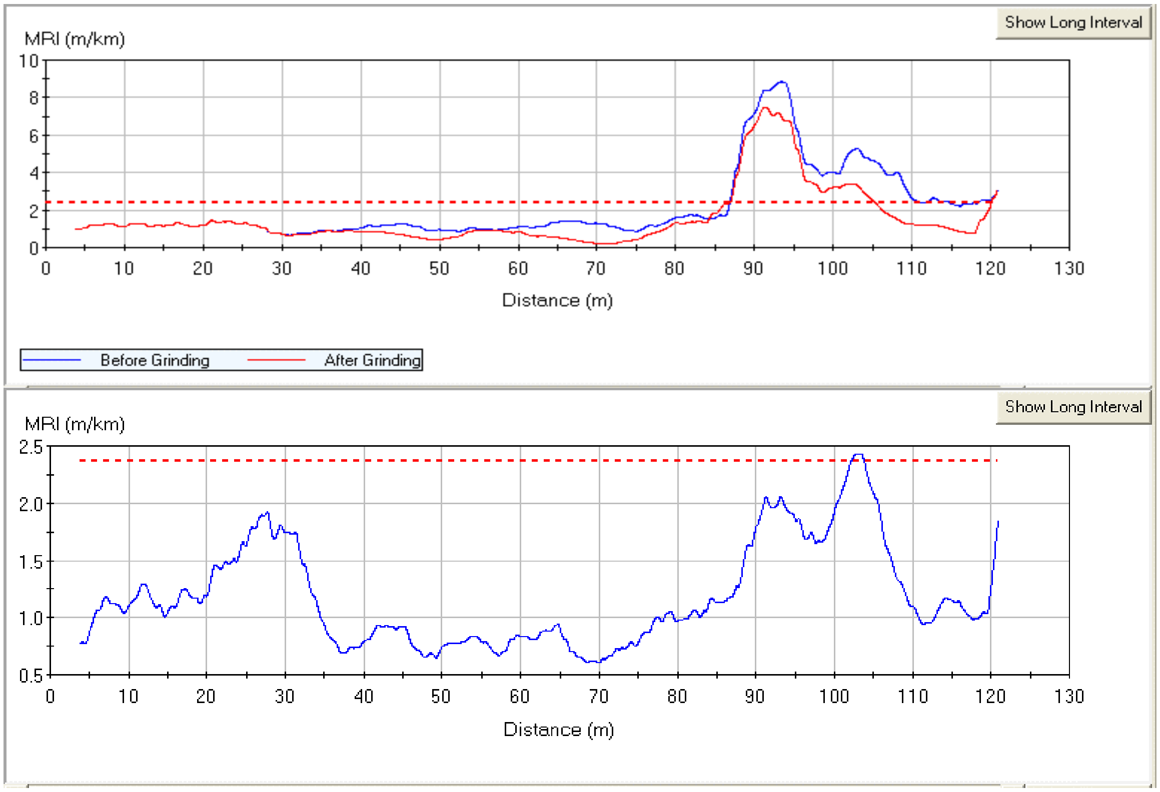


Figure 8. Before / Predicted IRI of grinding and actual IRI after grinding with grinder induced roughness.

The pavement leading up to the bridge in the right lane southbound direction was ground with one forward pass full width of the lane. Although the ProVAL grinding simulation predicted only minor improvement, it was decided to grind this section as the grinder was already going to be in the vicinity to grind the left wheel path. The grinding foreman had also stated that he could make significant improvement by doing so. Figure 9 graphically shows the predicted and actual improvement.

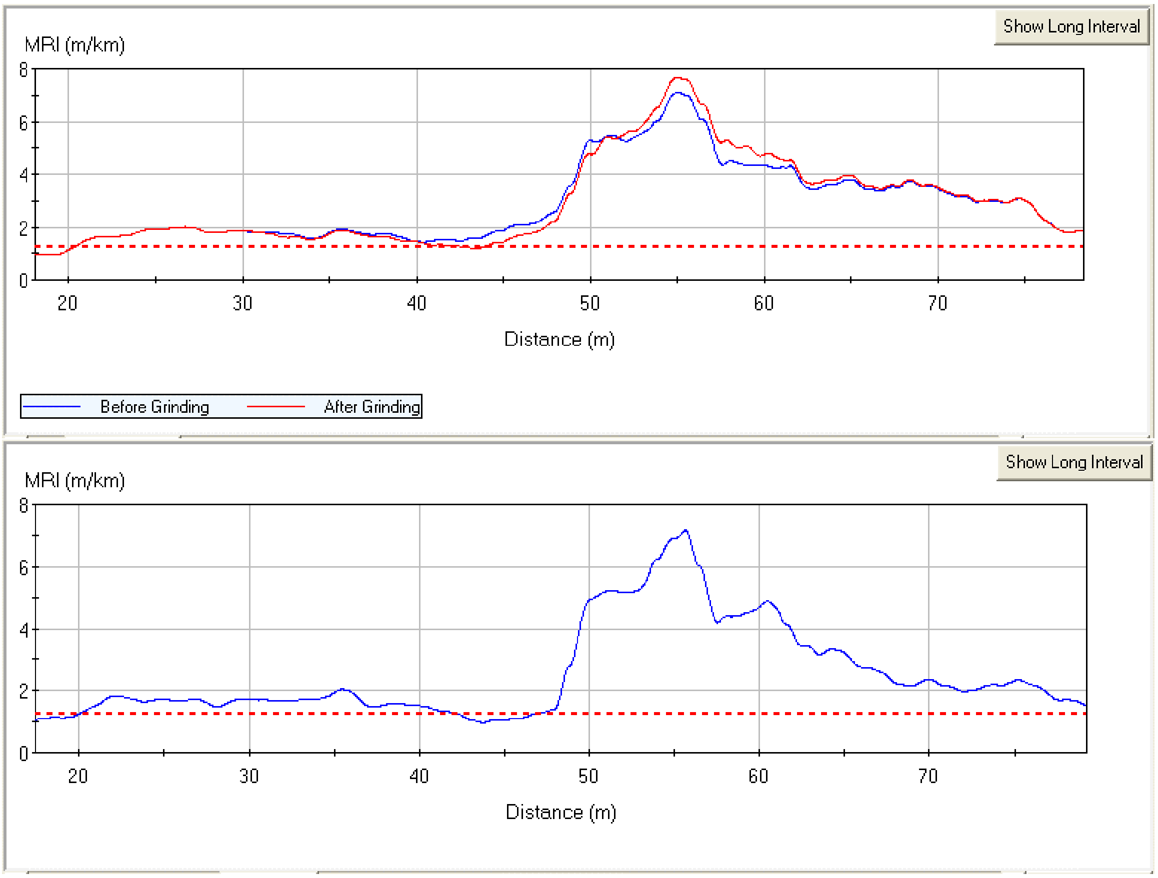
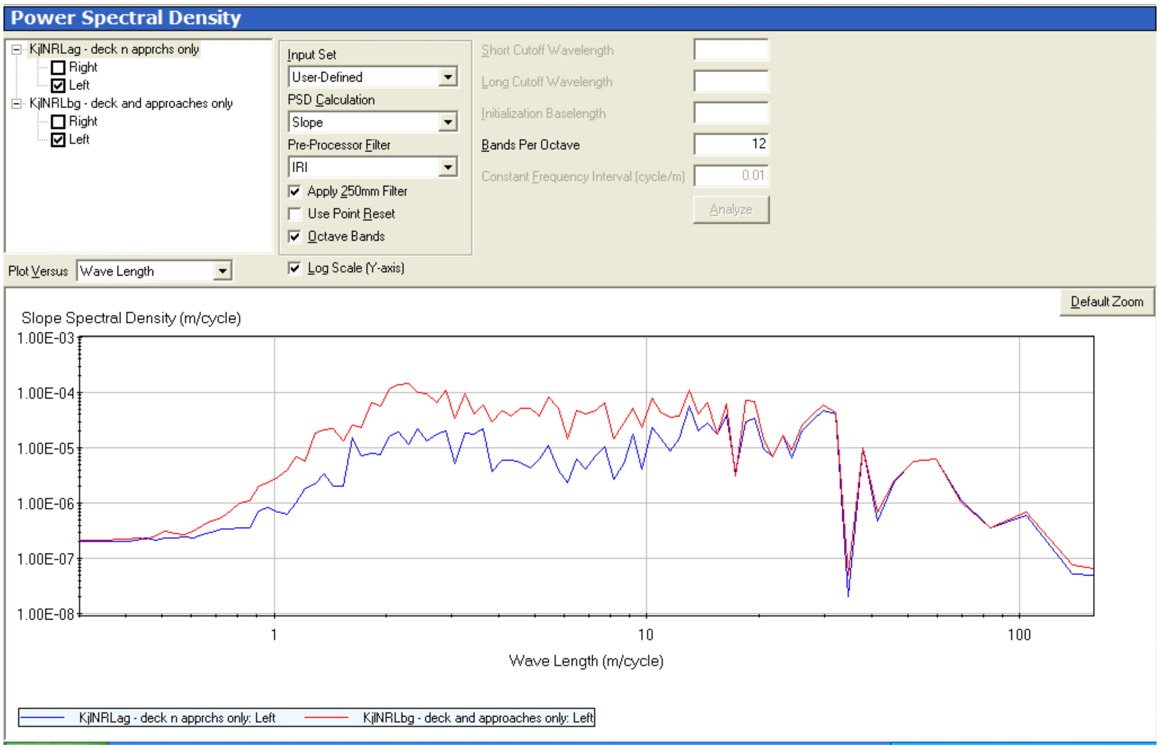


Figure 9. Before / predicted and actual IRI of southbound right lane entry to bridge.

A diamond grinder is limited by its geometry in what roughness content it can improve. Bumps in the profile are more likely to be ground down while dips may not be improved and possibly only lengthened. The grinder used on this project had a wheel base of 5.5 m (18 feet) between the pivot points of the front axle and rear tandem axles. Roughness events less than the wheel base are more likely to be improved by grinding. As roughness events exceed the wheel base of the machine, the benefit of grinding attenuates until the grinder just follows the existing road profile. This can be evidenced by Power Spectral Density (PSD) analysis (Sayers & Karamihas, 1996). The PSD analysis was used to plot the roughness energy of the profile by wavelength. Figure 10 shows such analysis before and after profiles of the left wheel path northbound right lane. It has been pre-filtered for wavelengths of roughness that affect the IRI statistic.



Power Spectral Density

- KjINRLag - deck n apprchs only
  - ☐ Right
  - ☑ Left
- KjINRLbg - deck and approaches only
  - ☐ Right
  - ☑ Left

Input Set: User-Defined
PSD Calculation: Slope
Pre-Processor Filter: IRI
☑ Apply 250mm Filter
☐ Use Point Reset
☑ Octave Bands
☑ Log Scale (Y-axis)
Plot Versus: Wave Length
Short Cutoff Wavelength:
Long Cutoff Wavelength:
Initialization Baselength:
Bands Per Octave: 12
Constant Frequency Interval (cycle/m): 0.01

Figure 10. PSD analysis of profiles before and after grinding.

Table 2. IRI for lanes before and after grinding.

	IRI (m/km)					
	NORTHBOUND RIGHT LANE			SOUTHBOUND RIGHT LANE		
	LWP	RWP	AVERAGE	LWP	RWP	AVERAGE
BEFORE	4.74	2.23	3.49	3.89	2.47	3.18
AFTER	1.86	1.83	1.85	2.11	2.36	2.23
REDUCTION	2.51	0.40	1.64	1.78	0.11	0.95

Table 2 shows the overall improvement of ride before and after grinding of the outside lanes from 30.5 m (100 feet) ahead to 30.5m 100 (feet) after the bridge.

4 CONCLUSIONS

Diamond grinding on this project significantly improved rideability through the bridge encounter. This case study demonstrated that the grinding simulation in ProVAL is a useful tool at predicting rideability after grinding. The specific predictions versus actual results on this project suggest that the simulation underestimates the improvement that can actually be achieved. It further demonstrated that grinding simulator is a useful tool in developing and maximizing grinding strategies.

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