

USE OF PROFILE DATA TO DETECT CONCRETE PAVING PROBLEMS

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Abstract

The ride quality of a pavement is extremely important to road users. Research has shown that pavements that are built smoother provide a longer service life. Because of these benefits, highway agencies have implemented smoothness specifications to promote construction of pavements that provide road users with the ride quality they expect. A smoothness specification indicates the smoothness level that a contractor must achieve to obtain full payment. In the United States, there is a growing trend of using inertial profilers to collect smoothness data on new portland cement concrete (PCC) pavements and to use the International Roughness Index (IRI) that is computed from the profile data to judge the level of smoothness. Lightweight inertial profilers can collect data on PCC pavement as soon as the PCC has hardened. Repetitive features as well as localized roughness features that are introduced to the pavement profile during paving can be easily detected by analyzing data collected by inertial profilers. This paper illustrates how filtering techniques and power spectral density (PSD) plots can be used to analyze profile data and detect paving problems. The detection of following paving problems from profile data are illustrated in this paper: stringline sag, roughness caused by dowel effects, mechanical oscillating floats, and headers.

Introduction

In 1996, the Federal Highway Administration (FHWA) commissioned a national survey of frequent highway users that asked questions about what they wanted in their highway “product.” The highway users clearly stated that road condition was their top priority, followed by safety and reducing congestion (Swanlund 2000). Research has shown that pavements that are built smoother provide a longer service life. (Perera and Kohn 2001, 2004; Smith 1997). Because of the benefit provided to

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road users by building smooth pavements and the longer service life provided by smooth pavements, highway agencies have implemented smoothness specifications for new pavements to promote construction of smooth pavements. A smoothness specification indicates an acceptable range of smoothness that a contractor must achieve to obtain full payment. Highway agencies usually give bonuses to contractors who obtain better smoothness than the specified level, while assessing penalties if the smoothness is less than the specified level.

In the United States there is a growing trend of using inertial profilers to collect smoothness data on new portland cement concrete (PCC) pavements and to use the International Roughness Index (IRI) that is computed from the profile data to judge the level of smoothness. It has been shown that the IRI has a good correlation with the roughness felt by the road users (Sayers and Karamihas 1997; Shafizadeh et. al. 2002).

Lightweight inertial profilers can collect data on PCC pavement as soon as the PCC has hardened. Repetitive features that are introduced to the pavement profile during paving can be easily detected by analyzing data collected by an inertial profiler. Performing profile measurements immediately after each day's paving and then analyzing the data can help determine if there are problems in the paving process that introduces roughness into the pavement.

This paper presents several examples that demonstrate how profile features that affect smoothness can be detected by analyzing profile data and how these features impact smoothness. Early detection of such problems can avoid these features from being re-introduced into the project by developing a suitable remedy. This paper illustrates how filtering techniques and power spectral density (PSD) plots can be used to analyze profile data and detect paving problems. The ProVAL software (FHWA 2007) developed by the FHWA has the capability of performing these analyses. This software can be downloaded free of charge from the internet.

This paper presents how the following factors influence the profile and roughness of the pavement:

- Stringline sag.
- Dowel effects.
- Use of mechanical oscillating floats.
- Headers.

Stringline Sag

The stringline is the guidance system for the slipform paver. The elevation sensing wand of the paver rides beneath the string and the pavement profile matches the stringline profile. A sag in the stringline will result in a pavement profile that is comprised of concave shaped arcs, with the length of an arc being equal to the distance between the stringline support stakes. The effect of stringline sag can be easily detected in the profile data. Figure 1 shows a pavement profile obtained by an inertial profiler on a pavement that shows the effects of stringline sag. The profile has been high-pass filtered to obtain a clear view of the profile features. The stringline support stakes in this project were spaced at 6.7-m intervals, and the pavement profile

consists of a series of 6.7-m long concave shaped arcs. The IRI of this profile over a distance of 161 m was 2.37 m/km.

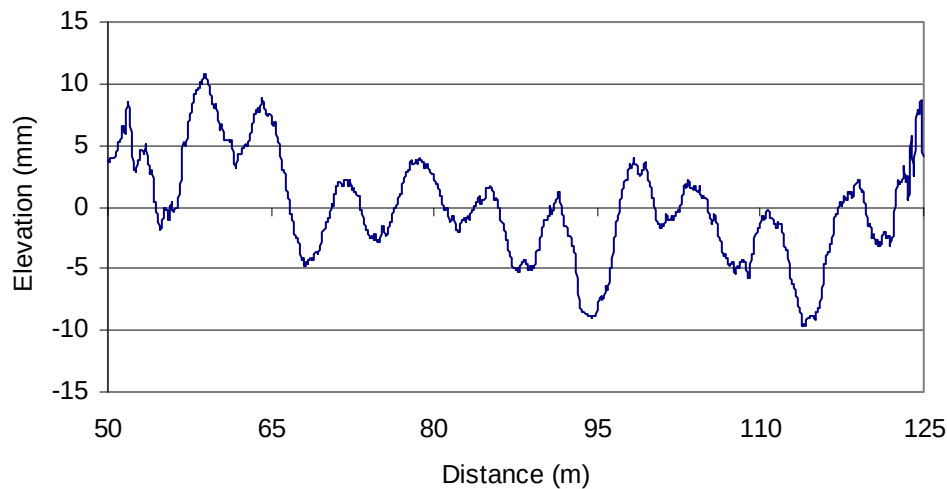


Figure 1. Pavement profile resulting from stringline sag where stringline supports were at 6.7-m intervals.

A road profile encompasses a spectrum of sinusoidal wavelengths. A PSD function is a statistical representation of the importance of various wavelengths contained in the profile (Sayers and Karamihas 1997). The PSD plot of the profile data shown in figure 1 is presented in figure 2. This plot shows the wavelength of 6.7-m dominates the profile. This indicates most of the roughness in the profile is contributed by the 6.7-m wavelength. This wavelength is caused by stringline sag, where the spacing between the stringline supports is 6.7-m.

Figure 3 shows another example of stringline sag, where the stakes supporting the stringline were at 15.2-m intervals. Data for this case were also collected with an inertial profiler. The profile data shown in figure 3 have been band-pass filtered, and the profile of the right wheel path has been offset for clarity. The stringline support stakes in this pavement were spaced at 15.2-m intervals, and hence each concave shaped arc is 15.2-m long.

Rasmussen et. al. (2004) performed a theoretical analysis to determine the effect of stringline sag on IRI for stake spacings of 7.6 and 15.2 m. They studied how stringline sag will increase the IRI of a pavement that had an IRI of 0.88 m/km without any stringline sag. For a 7.6-m stake spacing, stringline sags of 2.5, 5.1, and 12.7 mm resulted in IRI values of 1.11, 1.63, and 3.61 m/km respectively, which is an increase in IRI of 27, 84, and 309 percent respectively. For a 15.2-m stake spacing, stringline sags of 2.5, 5.1, and 12.7 mm resulted in IRI values of 0.99, 1.23, and 2.23 m/km respectively, which is an increase in IRI of 12, 39, and 154 percent, respectively. These results clearly show that stringline sag can have a significant effect on the IRI.

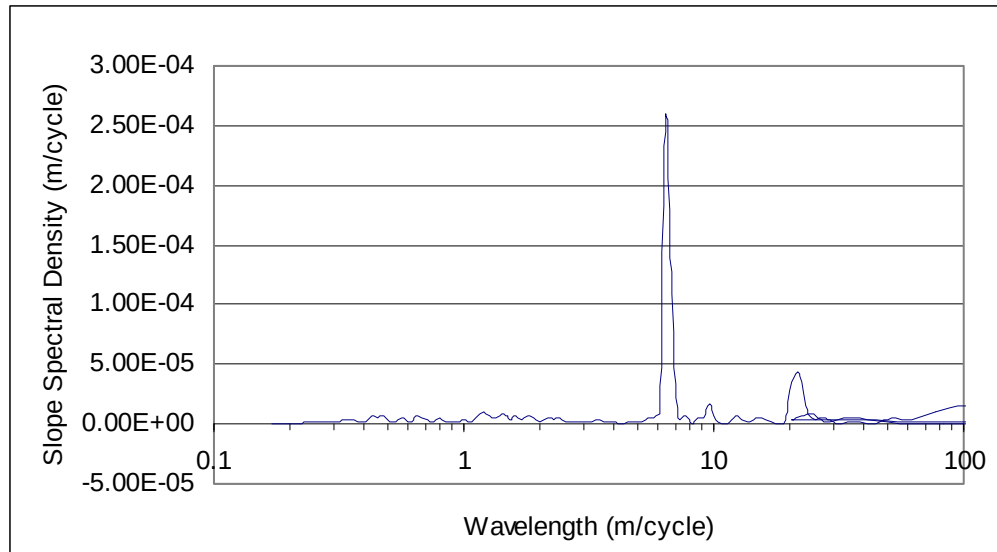


Figure 2. PSD plot of profile with stringline sag (stringline supports were at 6.7-m intervals).

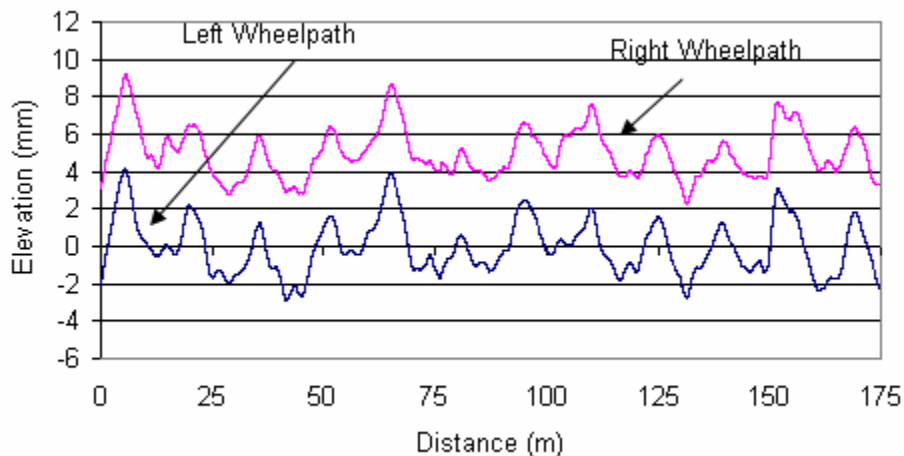


Figure 3. Pavement profile resulting from stringline sag where stringline supports were at 15.2-m intervals.

Air temperature and relative humidity variations during the day can cause sags in the stringline (ACPA 2003). Therefore, very close attention should be paid to the stringline during paving to make sure that it is taut. The roughness created by stringline sag cannot usually be corrected by spot grinding. The entire project would have to be ground to correct the problem, with the grinding depth increasing with the amount of sag.

Dowel Effects

In an experiment conducted in Iowa, pavement profiles were obtained immediately behind the profile pan of the paver by attaching sensors to the back of the paver. In

this project, the dowel baskets were placed on the base prior to paving. Figure 4 shows a portion of the collected profile data that has been subjected to a high-pass filter to show short wavelength roughness. The profile shows bumps at 6.1-m intervals, which is the joint spacing of the pavement, which also corresponds to the dowel basket locations. These bumps are believed to be caused by the dowel basket spring-back effect. Dowel spring-back occurs when the dowel basket assembly deflects when the profile pan of the slipform paver passes over the assembly, and thereafter springs back after the pan passes over and the extrusion pressure is released. A review of the collected data indicated that the magnitude of the height of the bumps at dowel locations varied, and the bumps were not seen at some dowel locations.

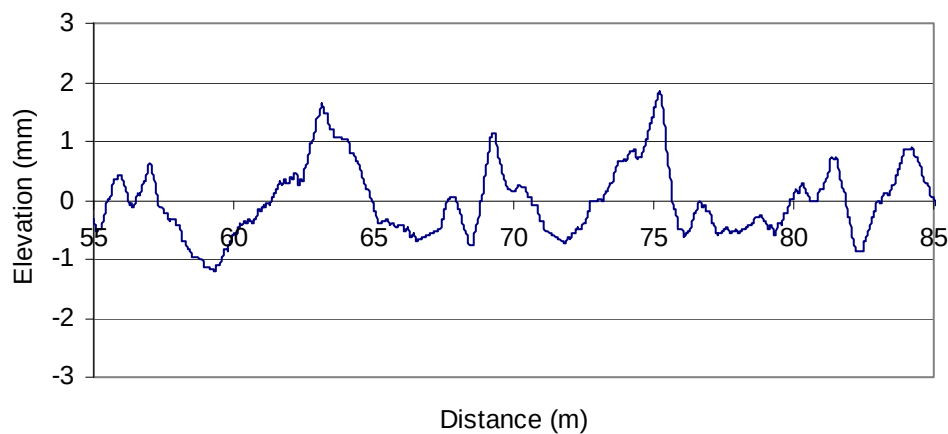


Figure 4. Dowel basket spring-back effect in profiles measured immediately behind the paver.

Profile data were also collected on this pavement using a lightweight inertial profiler after the concrete had hardened. Cones were placed at every other joint location, and the profiler recorded event marks in the profile data at the cone locations. A portion of the collected data are shown in figure 5, with the data being subjected to the same high pass filter that was applied to the data shown in figure 4. This profile also shows bumps in the profile at 6.1-m intervals. The bump locations seen in the profile coincided with joint locations that were determined from the event marks made during profiling, which verified that the bumps were occurring at the joint locations. A PSD analysis indicated that on the hardened concrete the magnitude of the bumps was less when compared to the bumps observed immediately behind the profile pan of the slipform paver. This indicates although the finishing operations performed on the pavement was able to reduce the disturbance caused by dowel spring-back, the effect could not be eliminated completely.

Figure 6 shows a continuous IRI plot based on a 6-m base length for the left wheel path of a section of new pavement on I-80 in Iowa. In a continuous IRI plot, the IRI at a location is the average roughness over the base length that was used in the plot with the base length being centered at that location. For example, in figure 6, the IRI shown at 88 m is the average IRI from 85 to 91 m. Dowel baskets were fixed to

the base in this project with the joint spacing being of this pavement being 6-m. tining. The profile data used to generate the roughness plot were collected using a lightweight inertial profiler. The profiler initiated data collection at a joint, and the joint locations in the profile were determined based on the joint-pacing, and are shown as vertical lines in figure 6. It can be seen that many of the peaks in the continuous IRI plot are occurring at or very close to joints. This indicates a likely effect of dowel spring-back occurring at the joints, which is resulting in a higher IRI value close to the joint location.

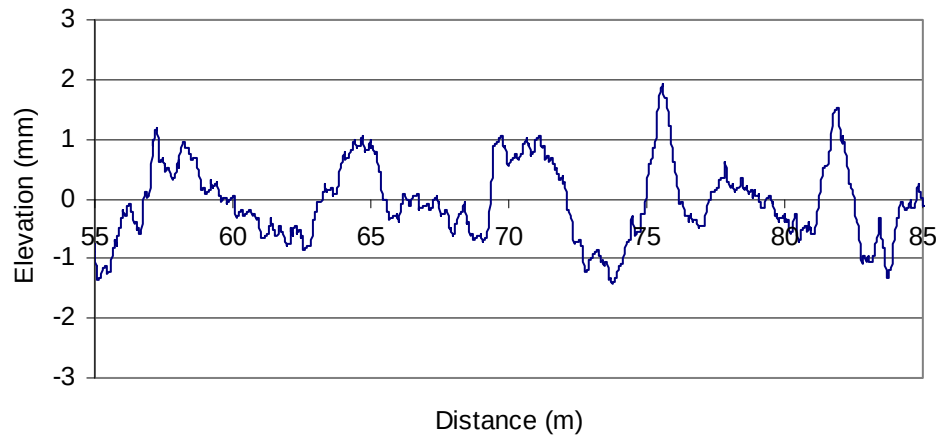


Figure 5. Dowel basket spring-back effect seen in the profiles measured on hardened concrete.

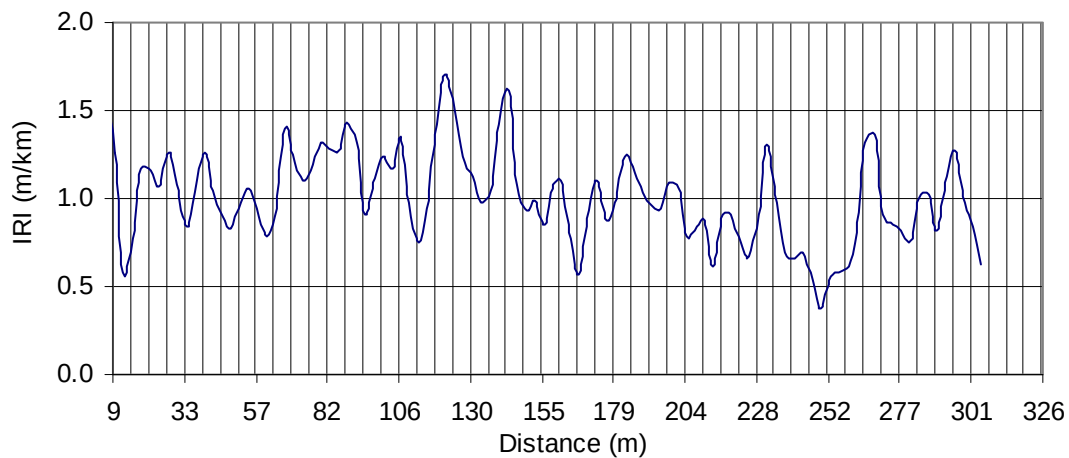


Figure 6. Continuous IRI plot based on a 6-m base length for a pavement section on I-80 in Iowa.

It has been reported that some contractors find that placing some concrete over dowel assemblies before the passage of the paving machine eliminates dowel assembly shoving and extrusion pressure effects (ACPA 2003). Using a well graded mix that is easily flowable as well as fixing the dowels firmly to the base can also

minimize the effect of dowel spring-back. ACPA (2003) reports that it is thought that the dowel spring-back effect is more pronounced where agencies require dowel basket tie wires (or spacer wires) to be cut before paving, thus weakening the assembly. ACPA (2005) reports that although some agencies allow these wires to be uncut, around 20 state agencies require concrete paving contractors to cut the tie wires prior to placing concrete. The intent of cutting the tie wires is to eliminate or reduce the apparent potential of the steel wires to lock the joint or for the wires to cause micro-cracking in the early ages of the concrete (ACPA 2005). It has been reported that leaving the tie wires intact will strengthen the dowel basket making it more resistant to movement and deflection while paving (ACPA 1991). ACPA (2005) reports that an analysis has shown that the tie wires will either fail by yielding of the wires or the weld holding the wires to the basket will fail before the wires can cause damage to the concrete or lock the joint. ACPA (2005) recommends leaving the wires intact, and indicates the benefits of leaving the wires intact far outweigh any remote possibility of increased risk of early distress in the concrete pavement. Instead of using dowel baskets placed on the base, equipment mounted on the slipform paver can be used to insert dowels into the pavement during paving. This method will eliminate the dowel spring-back problem.

Disturbances at a joint can also be created by dowel bar insertion equipment. Issues related to dowel bars at the joints can be detected by analyzing the profile data. These effects may not be clearly seen by looking at a profile plot. These effects will be more pronounced when the data are high-pass filtered to eliminate long wavelengths. If disturbances are seen in the profile that occur at an interval equal to the joint spacing, a dowel related effect influencing the profile can be suspected. Sometimes these disturbances may not be occurring at all joints. In such cases, some features can have a spacing equal to the joint spacing while other features may have a spacing equal to multiples of joint spacing. The effect of dowels can also be investigated by generating a continuous roughness plot as shown in figure 6. If peaks in the roughness plot are occurring at a spacing equal to the joint spacing or multiples of joint spacing, a dowel related issue influencing the profile can be suspected. When such features are noticed, the contractor can investigate the cause, and take steps to remedy the situation.

Mechanical Oscillating Floats (Automated Float)

A mechanical oscillating float, also called an automated float is sometimes used behind the paver to finish the concrete. A photograph of an automated float is shown in figure 7.

Profile data collected on a 183-m long section of US-20 in Iowa indicated the IRI values of the left and the right wheel paths to be 1.18 and 1.65 m/km, respectively. The IRI of the right wheel path was 40 percent higher than that of the left wheel path. This jointed plain concrete pavement has a 6.1-m joint spacing, and the profile data were collected using a lightweight inertial profiler.

Figure 8 shows plots of profile data collected along the left and right wheel paths on this pavement segment. The profiles have been band-pass filtered and the profile of the right wheel path has been offset for clarity. Evaluation of the profile

data indicated that the right wheel path had a repetitive feature having a wavelength of 1.6 m, but this feature was not seen in the left wheel path. As seen in figure 8, the right wheel path has more waviness when compared to the left wheel path.



Figure 7. Automated float behind the paver.

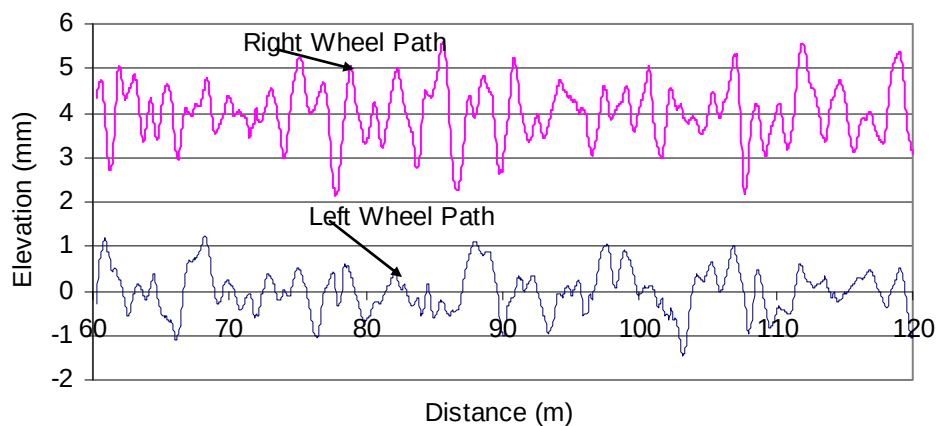


Figure 8. Profile data from a project in Iowa where an automated float was used.

The PSD plots of the left and right wheel path data for this segment are shown in figure 9. The plot shows a peak in the right wheel path at a wavelength of 1.6 m, which indicates profile features having a wavelength of 1.6 m have a significant contribution to the roughness of this section. Also, the right wheel path had more spectral content than the left wheel path for wavelengths between 0.5 and 3.5 m,

which also contributed to the higher roughness of the right wheel path. A 1.8-m long automated float was used behind the slipform paver in this project to finish the concrete. It appears that this float contributed to the repetitive waves that were noted along the right wheel path.

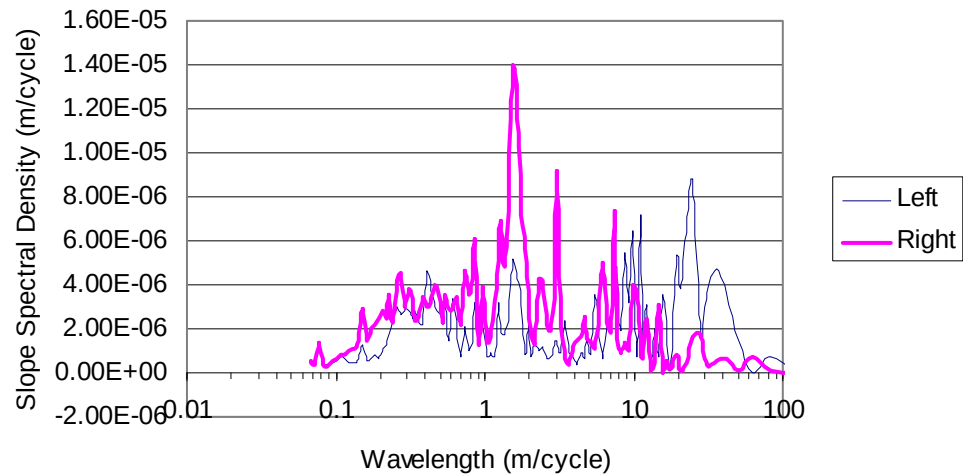


Figure 9. PSD plot of profile data from US-20 project.

A similar problem was noted at a project in Ohio that used an automated float. In this project, a new pavement was constructed for the realignment of US-33. A slipform paver was used to place the concrete and the dowel bars were inserted into the pavement during paving. Figure 10 shows the high-pass filtered profile data for a portion of this pavement. The data were collected with a high-speed profiler. A repetitive wave is seen in the right wheel path, and this feature is not seen in the left wheel path.

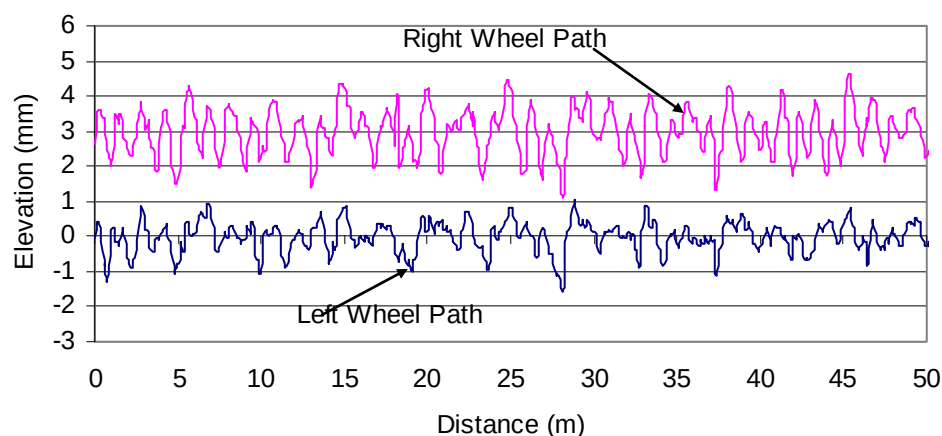


Figure 10. Profile data from a project in Ohio where an automated float was used.

Analysis of this data using a PSD plot indicated the repetitive wave seen in the right wheel path had a wavelength of 1.3 m. The PSD plot for this data is shown in

figure 11. As seen in this figure, the spectral content having a wavelength of 1.3 m is extremely prominent along the right wheel path when compared to the left wheel path. The left and right wheel path IRI of a 161-m long section on this roadway was 0.96 and 1.58 m/km, respectively. The IRI of the right wheel path was 65 percent higher than that of the left wheel path. It is believed that the automated float contributed to the repetitive wave seen in the right wheel path.

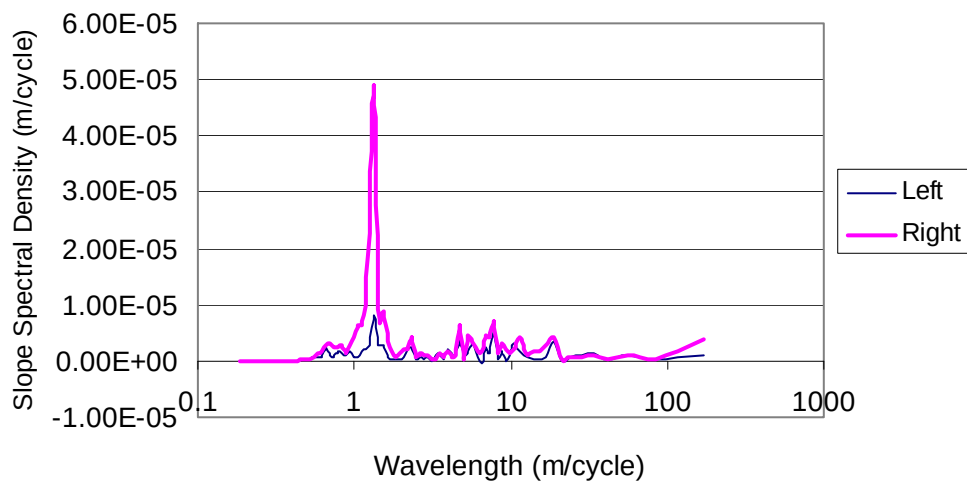


Figure 11. PSD plot of profile data from US-33 project in Ohio.

A slipform paver with an automated float behind it was used on a construction project on US-34 in Iowa, where the dowel baskets were fixed to the base (Cable et. al. 2005). In this project, sensors were used to measure the profile immediately behind the paver pan and also behind the automated float. One sensor was attached to the slipform paver pan, and a truss system mounted on the paver was used to measure the profile immediately behind the automated float. Both these sensors were mounted along the same path. Once the concrete hardened, the pavement was profiled by a lightweight profiler. The sensor mounted on the paver indicated a spring-back effect of the dowel baskets, as disturbances were noted on the profile at 6.1-m intervals, which was the distance between the dowel baskets. The profile obtained from the sensor immediately behind the automated float showed that the automated float was removing most of the effect on the profile caused by dowel spring-back. The data collected by the sensor behind the automated float showed good agreement with the data collected by the lightweight profiler. In this project, the automated float performed satisfactorily, eliminating most of the effect of dowel basket spring-back, and did not introduce any repetitive wavelengths to the profile.

If an automated float is used in a project, the contractor should make sure it is operating correctly by following the manufacturer's recommendations. If the float is not operating correctly, repetitive wavelengths can be introduced to the pavement, which will result in high roughness values. A significant amount of grinding may be needed to correct such a problem.

Headers

Headers are locations where a transverse construction joint is made at the end of a day's work, at an intersection, at a leaveout, or at a bridge. The most common practice in constructing a header is to place a wooden form to create a joint (ACPA 2003). The forming of a header in this manner increases the chances of a bump in the surface due to the handwork necessary to blend the mechanized paving surface with the hand placed area (ACPA 2003). Instead of hand forming headers, some contractors use a cut-back method to create a joint (ACPA 2003). In this method, the paver operator continues paving till all of the concrete is placed. When paving resumes the next day, a transverse saw cut is made where the surface depression ends, which may be 1.6 m or more from the end of the hardened slab. Thereafter, dowels are grouted into holes drilled into the header joint. Headers are typically locations of concentrated roughness.

Figure 12 shows a plot of profile data that were collected by a lightweight profiler along the right wheel path over a header about a day after paving. The data shown in figure 12 have been subjected to a high-pass filter in order to see short wavelength profile features clearly. These data were collected on US-23 in Michigan. The pavement is a jointed plain concrete pavement with a 4.6-m joint spacing and was paved with a slipform paver. The effect of the header is seen in the data from 406 to 418 m. This header was created using the cut-back method.

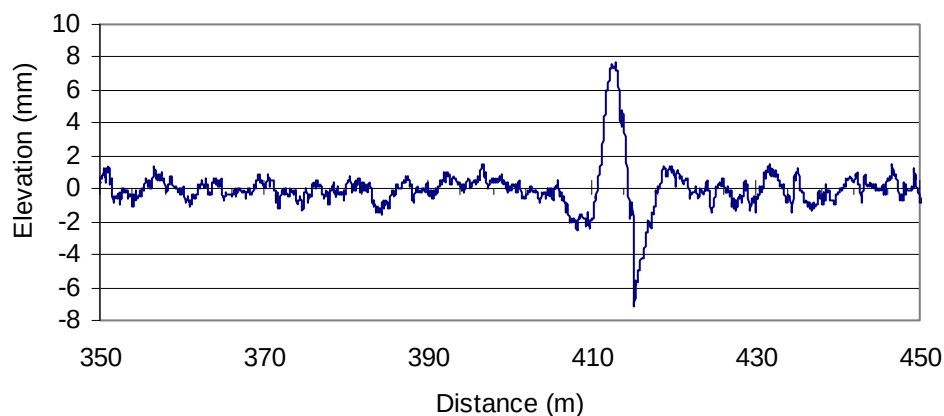


Figure 12. Data collected over a header on US-23.

Figure 13 shows a continuous IRI plot based on a 7.6-m base length for the right wheel path data starting from approximately 407 m upstream of the header, and ending about 55 m downstream of the header. Overall, this road is very smooth with an approximate IRI of 1 m/km. The peak IRI over this header based on a 7.6-m base length is 5.3 m/km. The roughness over the header is approximately five times that of the surrounding area. Profiles taken along the two wheel paths of both lanes showed that the peak IRI over the header based on a 7.6-m continuous IRI plot ranged from 3.0 to 5.3 m/km. This location is bound to be ground before the road is opened to traffic. For the profile shown in figure 12, the Smoothness Assurance Module in

ProVAL software indicated the peak IRI (based on a 7.6-m base length) can be reduced from 5.3 to 2.8 m/km by grinding. Although grinding will reduce the roughness, this location will still be felt by road users as a localized rough spot on a very smooth pavement.

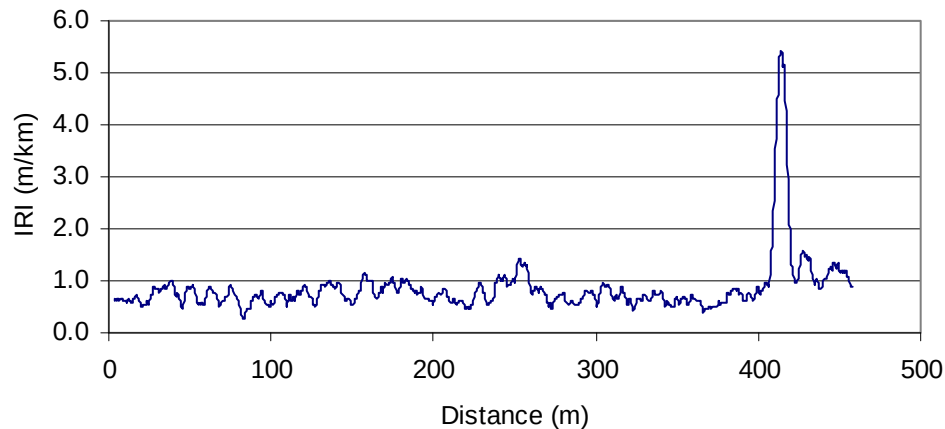


Figure 13. Continuous IRI plot of a pavement section with header, US-23.

Figure 14 shows a continuous IRI plot (based on a 7.6-m base length) generated from the data collected over a header by a lightweight profiler one day after paving on I-69 in Michigan. As shown in this figure, the peak IRI over the header was more than four times the IRI of the surrounding area. The Smoothness Assurance module in ProVAL software predicted the peak IRI over the header (based on a 7.6-m base length) can be reduced from approximately 4.4 to 2.2 m/km after grinding. However, the roughness level after grinding is still high, and this feature will be felt by the road users as a localized rough spot.

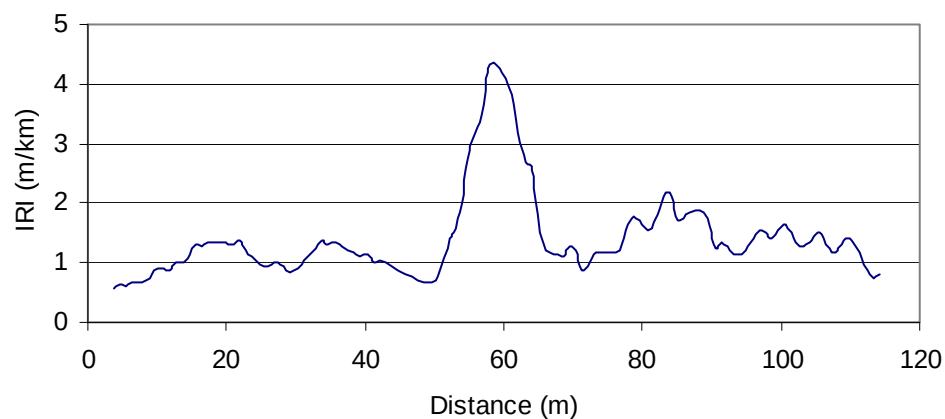


Figure 14. Continuous IRI plot for a section with a header, I-69.

These examples show that headers can have a significant effect on localized roughness. Contractors should be aware of this phenomenon and develop methods to

eliminate roughness occurring at headers. Road users can have a negative feeling about the ride quality of a road that has isolated areas of high roughness even though the road may have an acceptable ride quality overall.

Conclusions

Issues such as stringline sag, spring-back effect of dowel baskets, problems with dowel bar insertion equipment, or a mechanical float that is not working properly can introduce roughness into the pavement. The profile features that cause roughness due to these factors are generally repetitive along the project. Repetitive features introduced into the profile by these factors can be detected easily by analyzing the profile data. Analysis methods that can be used to detect these features include filtering techniques and evaluating PSD plots. If these issues are not identified early in the project and a suitable remedy developed to correct them, the entire project can be impacted by these issues. Grinding to correct profile problems caused by these issues can be extremely costly. Contractors should collect profile data after each day's paving and analyze the data to ensure that there are no paving problems that will affect smoothness. Headers that occur at the end of a day's work are locations of significant roughness. Although grinding can reduce some of the roughness, a header can still cause significant localized roughness. Careful attention should be paid during the construction of headers to minimize the roughness occurring at these locations.

Acknowledgments

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