**Paper Submitted for Pavement Evaluation 2002**

# PROFILING ERRORS AND HOW TO AVOID THEM


Rohan W. Perera. Ph.D, P.E.
Project Engineer
Soil and Materials Engineers
43980 Plymouth Oaks Blvd
Plymouth, MI 48170
Phone: (734) 454-9900
Fax: (734) 454-0629
E-mail: perera@plymouth.soilmat.com

and

Starr D. Kohn. Ph.D., P.E.
Vice President
Soil and Materials Engineers
43980 Plymouth Oaks Blvd
Plymouth, MI 48170
Phone: (734) 454-9900
Fax: (734) 454-0629
E-mail: kohn@plymouth.soilmat.com

**ABSTRACT**

High speed road profiling is a technology that began in the 1960's when Elson Spangler and William Kelley developed an inertial profiler at the General Motors Research Laboratory. Most state highway agencies in the United States use inertial profilers to collect profile data on their highway network, and use a smoothness index computed from the profile data for pavement management purposes. Several state highway agencies have now started to use a smoothness index such as International Roughness Index (IRI) that is computed from inertial profiler data for construction quality control. The acceptance of the new pavement, as well as bonus payments and levying of penalties are being based on this smoothness index. Therefore, it is extremely important that inertial profilers collect accurate profile data on such projects.

The three main components of a profiler are the height sensor, accelerometer and the distance measurement system. Problems in any of these components can compromise the quality of the profile data. Another important factor affecting the quality of the data is the operation of the profiler. Among profiler operational factors that have an effect on the data quality are operating speed of the profiler, speed changes during profiling, lead-in distance required prior to a section, lateral positioning within a section, and correct data initiation at the start of the section. Factors in the environment in which the profiler operates can also affect data quality. These factors include surface contaminants and surface moisture. This paper describes the effect of equipment factors, operational factors and environmental factors that influence the quality of profile data. This paper focuses on the effect of these factors on data collected on new pavements for construction acceptance. Procedures that should be followed to avoid errors during profiling are described.

## INTRODUCTION

Most highway agencies in the United States use high-speed profilers to collect smoothness data of their highway network for pavement management purposes. The profile data collected by inertial profilers are used to compute a smoothness index such as the International Roughness Index (IRI) of specific highway segments. Although state highway agencies use data from inertial profilers to keep track of smoothness of their highway network, profilographs are still the most common equipment that is used to evaluate the smoothness of new construction and rehabilitated pavements. The Profile Index (PI) that is computed from the profilograph trace is used as the basis of acceptance of new construction. The locations of "must grind" bump locations are also identified from the profilograph trace. The PI is also used for payment of incentives, or levying penalties. However, there have been questions raised about how well a profilograph measures wavelengths that are related to ride quality. Profilographs are known to amplify and attenuate the true pavement surface profile. This calls for question the suitability of using profilograph data for construction acceptance and suggests the need for refinement in evaluation procedures. Kulakowski and Wambold *(1)* reported that profilographs have varying response to wavelengths present on roadways. They report that profilographs measure some wavelengths correctly, amplify some wavelengths, and that some wavelengths are hardly measured

Because of these concerns, some state highway agencies have started to use data from inertial profilers to evaluate the smoothness of new and rehabilitated pavements for construction acceptance. Inertial profilers are capable of measuring the true profile of the pavement surface. Some highway agencies are using the IRI computed from the profile data to specify smoothness levels for construction quality control. The profile data collected by an inertial profiler can also be used to perform a profilograph simulation and obtain the PI of the pavement, as well as must grind locations.

As inertial profilers are increasingly used to measure the smoothness of new pavements, it is very important that these devices collect accurate profile data. As acceptance or rejection of the new construction, as well as bonus and penalties are based on the measurements obtained from profilers, it is important that the measurements obtained from these devices be error free. This paper will describe common profiling errors, and procedures to prevent these errors from occurring. This paper will focus on issues related to profiling of new pavements, but these procedures are applicable for measurements made for network level profiling too.

## INERTIAL PROFILERS

High speed road profiling is a technology that began in the 1960's when Elson Spangler and William Kelly developed an inertial profiler at the General Motors Research Laboratory *(2)*. Inertial profilers are able to measure the true profile of the road. Inertial profilers can be classified as high-speed profilers that are van based and lightweight profilers that are based on a utility vehicle. High-speed profilers as well as lightweight profilers are used to collect profile data on asphalt concrete (AC) pavements for construction acceptance. Lightweight profilers are widely used to collect data on portland cement concrete (PCC) pavements for construction acceptance, as they can be used to profile the pavement as soon as the PCC has gained sufficient strength to support the equipment.

A schematic diagram of an inertial profiler is shown in figure 1. The principal components of an inertial profiler are height sensor(s), accelerometer(s), a distance measuring system, computer software and hardware.

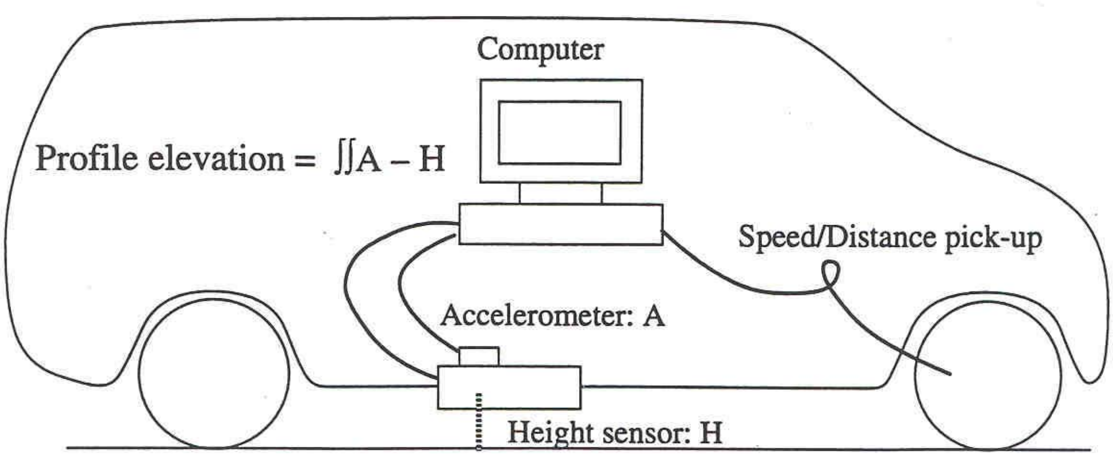


Figure 1. Components of an inertial profiler *(3)*.

The height sensor records the height to the pavement surface from the vehicle. The accelerometer that is located on top of the height sensor records the vertical acceleration of the vehicle. The acceleration is mathematically converted to vertical displacement. Data from the height sensor and the accelerometer is combined to determine the distance to pavement surface relative to an inertial reference frame. The distance measuring system keeps track of the distance with respect to a reference starting point. A computer program is used to compute the profile at each sampling point of the height sensor using the data recorded by the height sensor, accelerometer, and the distance measuring system. The non-contact height sensor types that are commonly used in profilers today are either laser or infrared.

A profiler can be equipped with a photocell to automatically initiate data collection at a pre-determined location. Two types of photocells, vertical and horizontal, are available. The vertical photocell can be used to automatically initiate data collection when the photocell detects a white reflective tape that is placed on the travel lane. The horizontal photocell is used with a traffic cone that has reflective markings that is placed on the shoulder to initiate data collection.

## FACTORS AFFECTING MEASUREMENTS MADE BY INERTIAL PROFILERS

For construction acceptance testing, the longitudinal profile of the pavement is measured along paths that are specified by the highway agency. The quality of the information that is obtained from the measured profile depends on the quality of the profile that is measured by the profiler. Various factors can affect the measurements made by inertial profilers. These factors can be categorized as: profiler equipment factors, profiler operational factors and measurement environment factors. The effect of each of these factors on profile measurements will be described separately.

## EQUIPMENT FACTORS AFFECTING PROFILE MEASUREMENTS

The three primary components of the profiler are the height sensor, accelerometer and the distance measuring system. An error in any of these three components will affect the quality of the profile data that are collected by an inertial profiler. Common errors that can occur in each of these components as well as procedures to ensure that these components are functioning properly are described separately for each component.

**Accelerometer**

In order to obtain accurate measurements from an accelerometer, it should be calibrated according to the procedures described by the manufacturer. An accelerometer that is out of calibration will read an inaccurate acceleration, and this inaccurate value will be used in the computation of profile, resulting in an incorrect profile. Sometimes, the accelerometer may not provide a signal because of a disconnected wire or a loose connection. The "Bounce Test" is a simple test that can be used to make sure that the accelerometers in the profiler are functioning correctly. This test also indicates if the height sensor is functioning properly. This test should be performed daily prior to data collection.

The "Bounce Test" is performed while the vehicle is stationary, using the software in the profiler. The vehicle is bounced while the vehicle is stationary, and the profile that is generated by the profiler is recorded. The bouncing motion in a high-speed profiler can be induced by standing on the rear bumper and inducing a rocking motion on the vehicle so that it moves up and down longitudinally. When data is collected using this procedure, the system is obtaining measurements at the same point, and therefore the profile that is generated should not show a bouncing pattern (the accelerometer corrects for the movement of the vehicle). If both the accelerometer and height sensor are working properly, ASTM E950 (*4*) indicates the profile that is generated should have an amplitude that is less than 1 percent of the motion that is induced on the sensors (i.e., if sensors are mounted on front bar, amplitude should be less than 1 percent of movement induced on front bar). If the accelerometer is not working properly, the height sensor reading will not be corrected for the vertical movement, and this will result in a profile that shows a very noticeable sine wave. Figure 2 shows an output from a bounce test that shows output from both the left and the right sensor. This figure clearly shows that the left sensor is not working properly. This may be caused by an error in the accelerometer or the height sensor. The left sensor shows a peak-to-peak movement of approximately 8 mm (0.3 in), which indicates an obvious problem with the sensor. Electronic components require some time to warm up and stabilize. Therefore, the equipment should be turned on for some time prior to performing the "Bounce Test." The time needed for the equipment to warm-up should be obtained from the profiler manufacturer.

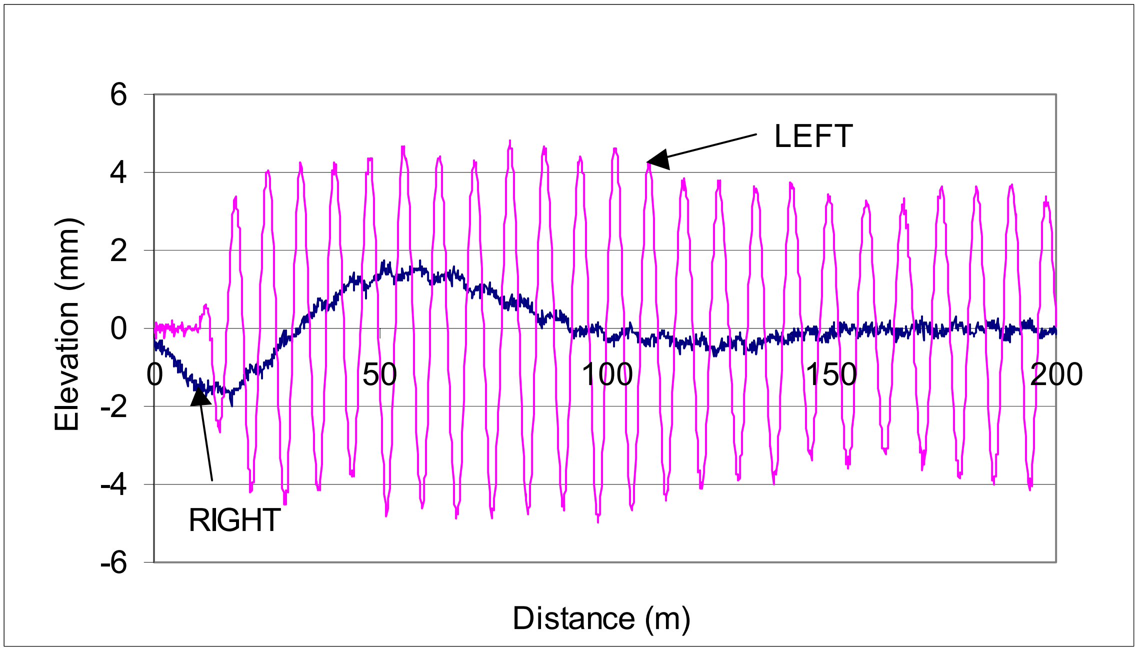


Figure 2. Bounce test output with an error in accelerometer of left sensor

The profilers used in the Long Term Pavement Performance (LTPP) Program evaluate the results of the bounce test by computing the IRI of the recorded profile (*5*). In the procedure used in the LTPP program, the profile is first recorded by turning the sensors on and recording the generated profile while the vehicle is stationary. In this condition, the "noise" in the system is recorded as profile. This condition is referred to as the static-bounce test. Thereafter, the operator induces a bouncing motion on the vehicle by bouncing the profiler in a longitudinal direction from the rear bumper of the vehicle to induce a peak-to-peak motion of 25 mm on the rear bumper. This test is referred to as dynamic bounce test. The IRI values of the profiles recorded from the static bounce test as well as the dynamic bounce test are then computed. The K.J. Law T-6600 profilers used in the LTPP program typically have a static bounce test IRI value of 0.06 m/km (4 in/mi). If high IRI values are obtained from the static bounce test, it indicates a problem in the sensor. The dynamic bounce test results in IRI values between 0.10 to 0.15 m/km (6 to 10 in/mi), with higher IRI values being obtained for older sensors. The bounce test results are considered to be satisfactory in the LTPP program if the difference between the dynamic bounce and static bounce IRI value is less than 0.10 m/km (6 in/mi).

During profiling, some profilers may emit a warning (audible warning or warning on screen) to indicate that signals are not being received from the accelerometer. Other profilers may not issue such a warning and just use the height sensor signal to compute the profile. This of course will result in an incorrect profile.

**Height Sensor**

The height sensor should read the measured height accurately. In order to obtain accurate measurements from a height sensor, it should be calibrated according to the procedures described by the manufacturer. Many profilers are equipped with Selcom laser sensors, and these sensors cannot be calibrated by the user (*6*). However, a check can be performed on these sensors to see if they can accurately measure height by using the procedure described in the following paragraph. A height sensor that is out of calibration will read an inaccurate height. This inaccurate value will be used in the computation of profile, and this will result in an incorrect profile.

A height sensor check can be performed to see if the sensor is functioning properly. This check involves using a gauge block of known thickness, and determining if the data acquisition system of the profiler can accurately measure the height of the gauge block. In the LTPP program, a static height sensor check is performed daily on each height sensor of the profiler prior to data collection to ensure that the sensors are working properly (*5*). This test is performed while the vehicle is stationary. The following procedure is used to perform this test:

1. Place a leveling plate below the height sensor and level the plate using three leveling screws in the plate.
2. Place calibration plate (which is a thin metal plate) on top of the leveling plate and take a reading using the data acquisition system of the profiler.
3. Place a 25 mm gauge block on top of leveling plate, place calibration plate on top of the gauge block, and take a reading using data acquisition system of profiler.
4. The difference between the readings obtained in step 3 and step 2 gives the height of the block as measured by the data acquisition system of the profiler. Compare this reading with

actual height of the block (25 mm). If the difference between the two readings is within ± 0.25 mm the height sensor is considered to be functioning properly.

The bounce test that was described earlier also serves as a check on the functioning of the height sensor. If the height sensor was not working properly, the resulting profile will only show the accelerometer signal and a sine wave pattern will be seen in the profile. However, the static sensor check is required in order to verify that the height sensor is measuring the height accurately.

Sometimes the height sensor may not be able to take readings because of problems such as loose wires or a loose connection. Some profilers may emit a warning (audible or on the computer screen) to indicate that signals are not being received from the height sensor. Some profilers may not issue such a warning, and simply use the accelerometer signal with whatever signal that is coming from the height sensor to compute the profile. This of course will result in an incorrect profile. Such errors are difficult to detect by looking at a profile plot.

The data obtained from the height sensor, accelerometer and distance measuring system are used by software in the inertial profiler to compute profile. Figure 3 shows an example of an output from the height sensor and the accelerometer, and the resulting profile that is obtained by combining the two outputs (*7*). The profile shown in figure 3 was obtained on a pavement that had cracks, and these cracks can be seen in the profile as downward spikes. If the measurements were obtained on a new pavement, the profile of the pavement as well as the height sensor reading will not show downward spikes and will show a smooth profile. If the height sensor was not working, and only the accelerometer signal was used to compute profile, it will be almost impossible to detect that there was a problem with the measurement by looking at the profile that was recorded by the profiler. A similar situation will occur if the height sensor was working and the accelerometer was not working. The point made here is that problems with the height sensor are very difficult to detect by looking at the recorded profile. Therefore, the static sensor check is a very important check to ensure that the height sensors are working correctly.

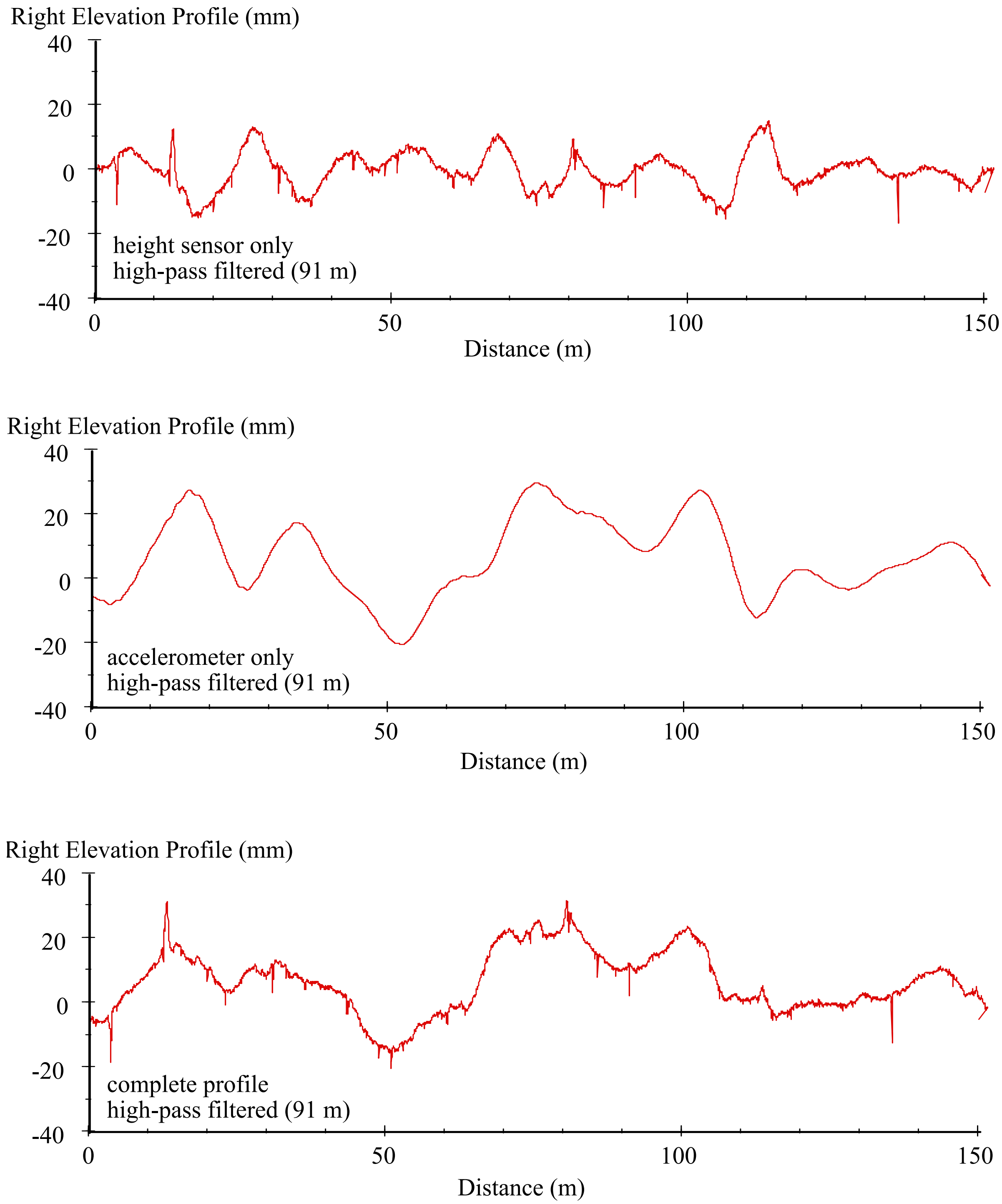


Figure 3. Output from height sensor, accelerometer and combined profile (*7*).

Some profilers are equipped with covers that are placed on the sensors to protect the sensor when the profiler is traveling between test sites. In some profilers, the profiler software may allow the collection of profile data even with the covers in place. Under such circumstances, the incorrect height sensor reading is used with the accelerometer signal to compute a profile. This will result in an incorrect profile. Figure 4 shows a profile that was collected on a road where the sensor cover was in place on the height sensor during data collection, as well as a profile that was collected with all components operating satisfactorily. As seen in this figure, the two profiles are very similar, and it is impossible to say that the height sensor signal was not being used in the computation of profile by looking at the profile plot. This type of error can be avoided if the profiler emits a warning if it detects that the height sensor signal is out of range.

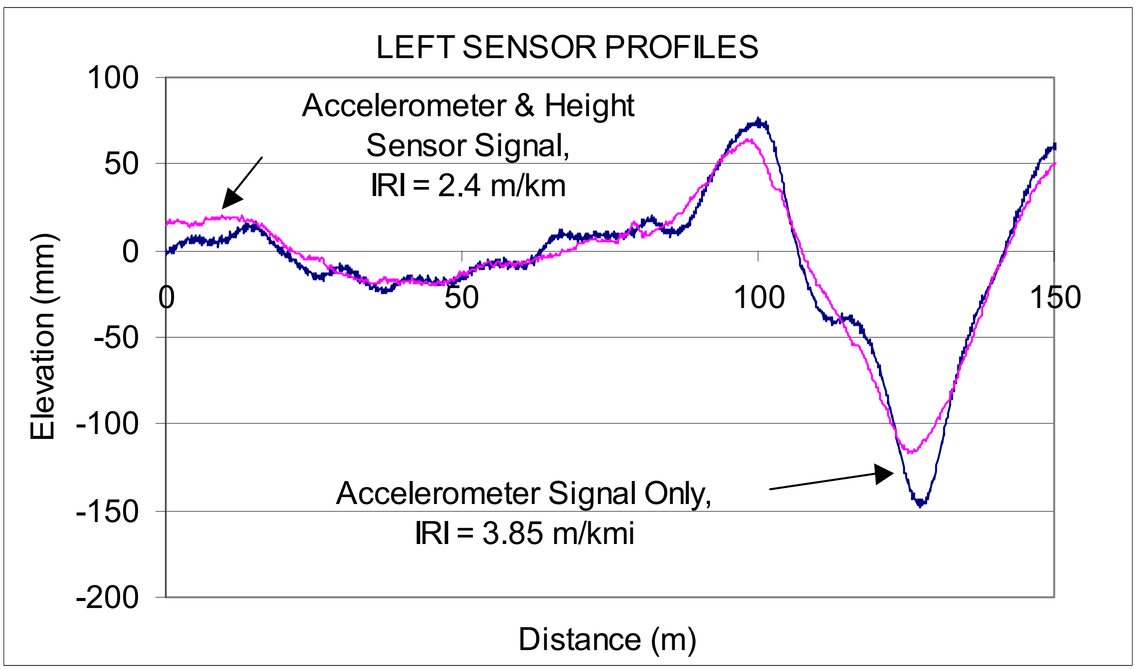


Figure 4. Effect of height sensor error on profile data.

**Distance Measuring System**

The profile recorded by an inertial profiler shows the variation of pavement profile with distance. Profiles that are collected for construction quality control are used to detect bump locations. In order to locate the roughness features in the field, the profile recorded by a profiler should accurately provide the distance to that feature from a reference station. Therefore, it is essential that the distance measuring system in the profiler be calibrated properly.

Table 1 presents the error in distance that occurs for a one-kilometer section for different percent errors in the distance measuring system. As seen in table, significant errors in distance can build up over distance if an error is present in the distance measuring system.

Table 1. Effect of errors in distance measuring system

| Percent Error in in Distance Measuring System (%) | Error in Distance (m) |
|---|---|
| 1 | 10 |
| 2 | 20 |
| 3 | 30 |
| 4 | 40 |
| 5 | 50 |
| 6 | 60 |

Figure 5 shows two profiles, one measured with an accurate distance measuring system and other measured with a system with a 5 percent error. The erroneous system measures a higher distance. As seen from this figure, the profile measured with the inaccurate system provides wrong locations for the profile features, and this can lead to a lack of faith in the profiling system, as a bump shown in the profile is not detected at that location in the field. An inaccurate distance measuring system will also result in incorrect roughness values being computed for specific pavement sections. Therefore, having a distance measuring system that is accurately calibrated is extremely important in profiling.

An error in the distance measuring system cannot be detected by examining the profile. The accuracy of the distance measuring system can be checked by using the profiler to measure the distance between two locations, whose actual distance is known. Then distance recorded by the profiler can be compared with the actual distance between the two locations to check the accuracy of the distance measuring system. In most profilers, the distance measuring system is attached to a front tire of the vehicle. The distance that is measured by the system depends on the rolling radius of the tire, which depends on the tire pressure. Therefore, the tire pressure of the wheel to which the distance measuring system is attached should be checked daily prior to operation. This tire pressure should be maintained when the distance measuring system is calibrated.

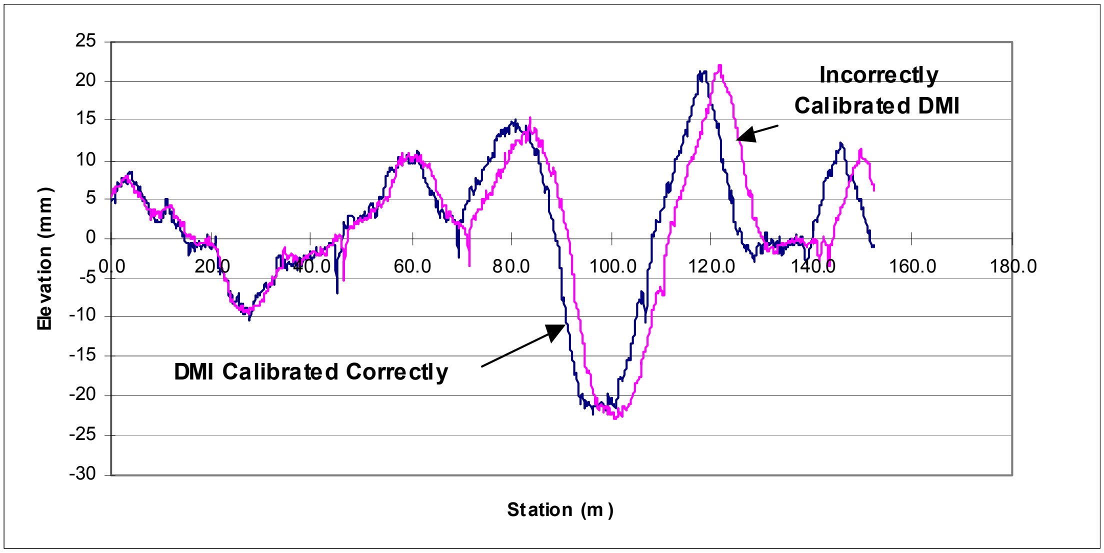


Figure 5. Effect of an incorrectly calibrated distance measuring system.

## PROFILER OPERATIONAL FACTORS AFFECTING PROFILE MEASUREMENTS

The profiler operator must ensure that the profiler is operated properly in order to collect accurate profile data. Operational factors that can affect the quality of the profile data include longitudinal positioning, operating speed, speed changes, lead-in distance and lateral positioning. The effect of each these factors on profile data are described separately.

### Longitudinal Positioning

The profiler initiates data collection at a reference station or a known location when profiling a pavement for construction quality control. In order to accurately compute the smoothness index, the data initiation must start exactly at the reference station. This is also very important in order to locate pavement features that are shown in the profile in the field. Profilers initiate data collection using either a manual method or an automated method. In the manual method a specific key in the computer keyboard is pressed when the operator determines the sensor is in line with the reference station. In the automated method, a photo-triggering device that is initiated by either a mark placed on the pavement surface or a cone with a reflective tape that is placed on the shoulder is used. When an automated method is used, data collection will start exactly at the reference location, while if a manual method is used there is bound to be an error in the start location relative to the reference station. This error will be higher for high-speed profilers when compared to lightweight profilers.

Figure 6 shows two profiles that were collected at a section. In one of the profiles, data collection started at the correct location, while in the other, profile data collection started 15 m (50 ft) before the correct location. If data collection is not initiated at the correct location, it will not be possible to locate profile features that are shown in the profile in the field. In addition, profile indices that are computed for specific pavement sections will not reflect the correct smoothness value of the section. Assume that the smoothness of the 150 m (500 ft) long section shown in figure 6 is required. If the data were actually collected 15 m (50 ft) before the section, the reported smoothness will be for the section 15 m (50 ft) before start of section to 135 m (443 ft) into the section instead of the section between 0 and 150 m (500 ft).

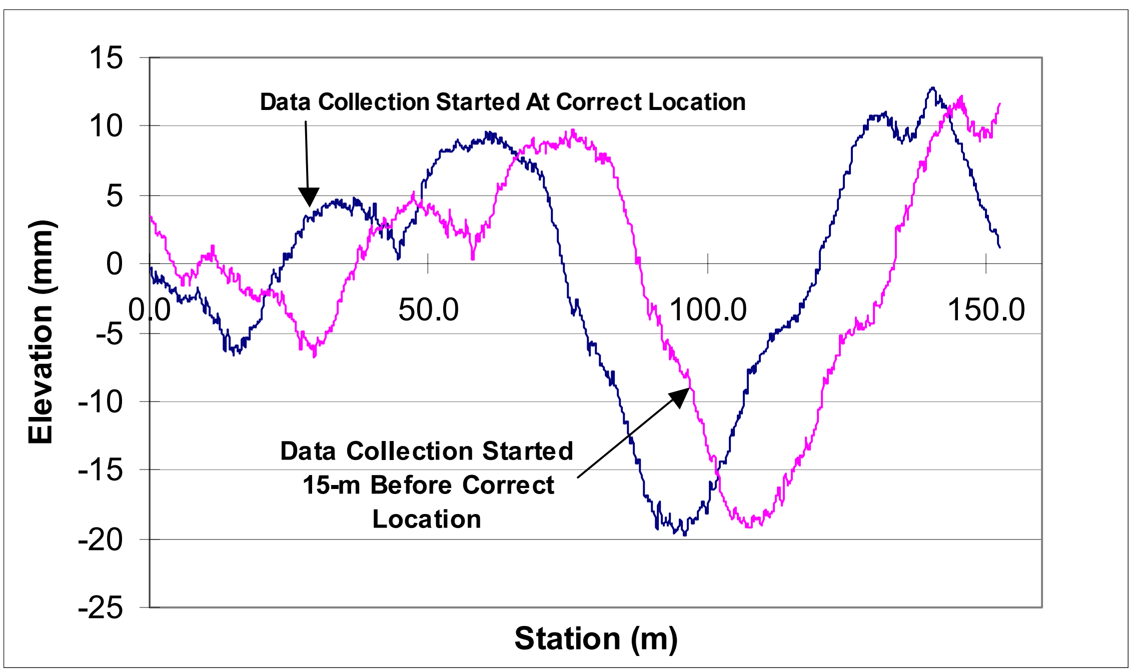


Figure 6. Effect of an incorrect data initiation location on profile data.

If repeat profiler runs are required at a section, using an automated method will ensure that the data collection for all repeat runs will all start at the exact location. If a manual method is used to initiate data collection, there is bound to be an offset between the different profile runs.

**Profiling Speed**

The profiler manufacturer specifies the range of speed over which valid profile data can be collected. If profile data are collected at speeds outside the valid range, this will result in the collection of erroneous data. Inertial profilers have to operate above a minimum operating speed in order to collect accurate data. The minimum speed at which a profiler should operate is dictated by the longest wavelength it needs to measure. An inertial profiler uses an accelerometer to sense vertical movement of the vehicle and establish an inertial reference. The amplitude of the accelerometer signal decreases rapidly as wavelength increases. At some cutoff wavelength, the amplitude of the accelerometer signal is so low that it is masked by sensor noise. The cutoff wavelength gets shorter at lower speeds, and at some low speed, a portion of the wavelength range of interest is affected. A common minimum operating speed for high-speed profilers is 25 km/h (15 mi/h). The profiler should be operated at a constant speed when collecting profile data.

*Effect of Speed Changes*

Speed changes during profiling can occur if the vehicle accelerates or decelerates during a profiling run. Research performed for NCHRP Project 10-47 indicated that accelerating or decelerating during a profile run could affect the profile data (*7,8)*. Either accelerating or decelerating the profiler causes a tilt in the accelerometer that affects the accelerometer readings, and this induces an error in the long wavelengths that are measured by the profiler. When collecting profiling data for construction acceptance purposes, the profiler must be up to its operating speed before the start of the section, and this speed should be maintained when profiling the section.

Figure 7 shows the effect of moderate braking on profile data of a high-speed profiler that was used for testing in NCHRP project 10-47 (*7*). This figure shows five runs that were collected by a high-speed profiler at a constant speed of 80 km/h (50 mi/h), and one run where moderate braking brought the speed of the profiler from 80 km/h (50 mi/h) to 48 km/h (30 mi/h). The braking affected the long wavelengths in the profile, and caused that run to look different from the other runs. However, the moderate braking had only a small effect on the IRI value (less than 5%). This was because IRI is only affected by wavelengths that are less than 30 m (100 ft).

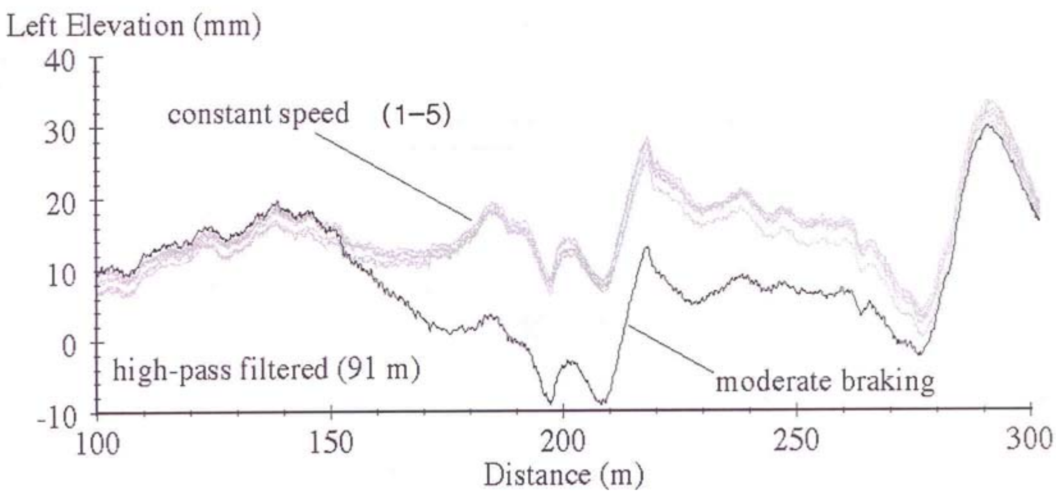


Figure 7. Effect of braking on profile data (*7*).

Accelerating during profiling runs also caused a change in profile shape because of the effect on long wavelengths. However, effect on IRI was small (*7*). It should be noted that the impact of acceleration and braking on IRI could be different for different profilers, and will depend on severity braking or acceleration that is applied.

A series of experiments that were performed with a lightweight profiler also showed that although the profile is somewhat affected by accelerating or decelerating within a profile run, the effect on the IRI was generally small. However, speed changes do have some impact on smoothness indices, and as far as construction quality tests are concerned, this impact can mean the difference between acceptance or rejection of a pavement section. Therefore, it is very important that the profiler maintain a constant operating speed when obtaining profile data.

*Stopping During a Profile Run*

Stopping and starting a profiler during a data collection run will introduce a major error on the collected data. Figure 8 shows a profile run with a lightweight profiler, where the profiler was stopped during the profile run at the middle of the run, and then it again started to collect data. A large downward spike is noted at the location where the profiler stopped during data collection. The IRI of the resulting profile was 3.1 m/km (196 in/mi), while the IRI of the section obtained from a profiler run that followed correct operational procedures was 1.6 m/km (101 in/mi). A profiler should never be stopped and restarted while collecting profile data. Data collected under such a condition will be erroneous. If a profiler has to stop during the middle of a profile run, the collected data should be discarded, and the section should be re-profiled.

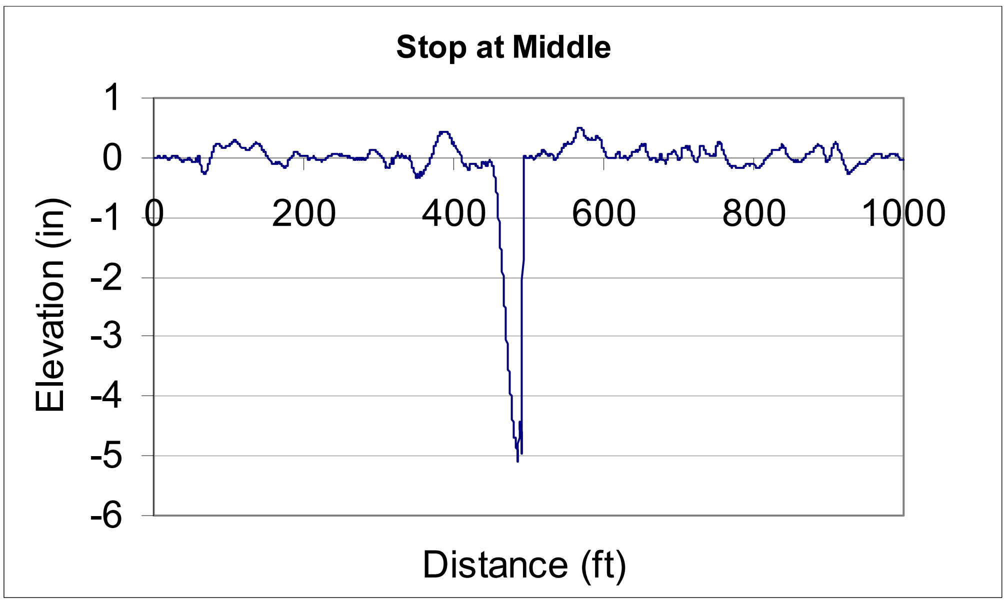


Figure 8. Effect of stopping a profiler during a profiler run.

**Lead-in Distance**

The profile data collection system in a profiler should be in operation prior to the location where data collection should begin in order for the filters that are used in profile computation to stabilize. The "lead in distance" refers to the distance prior to the test section that is required in order to collect accurate profile data. Details regarding the "lead in distance" that is required for the profiler should be obtained from the profiler manufacturer. Profilers also need a certain distance prior to the start of the section so they can come up to the operating speed.

If data collection at a section is initiated without a sufficient lead in prior to the test section, the data that is collected at the beginning of the section will be erroneous. Figure 9 shows the profile data that were collected at a section where a high-speed profiler started collecting data from a dead stop at the beginning of a section (*7*). This figure also shows a profile run where the data were collecting using correct operational procedures. As shown in this figure, the data collected for the profile run where the profiler started data collection from a dead stop is erroneous.

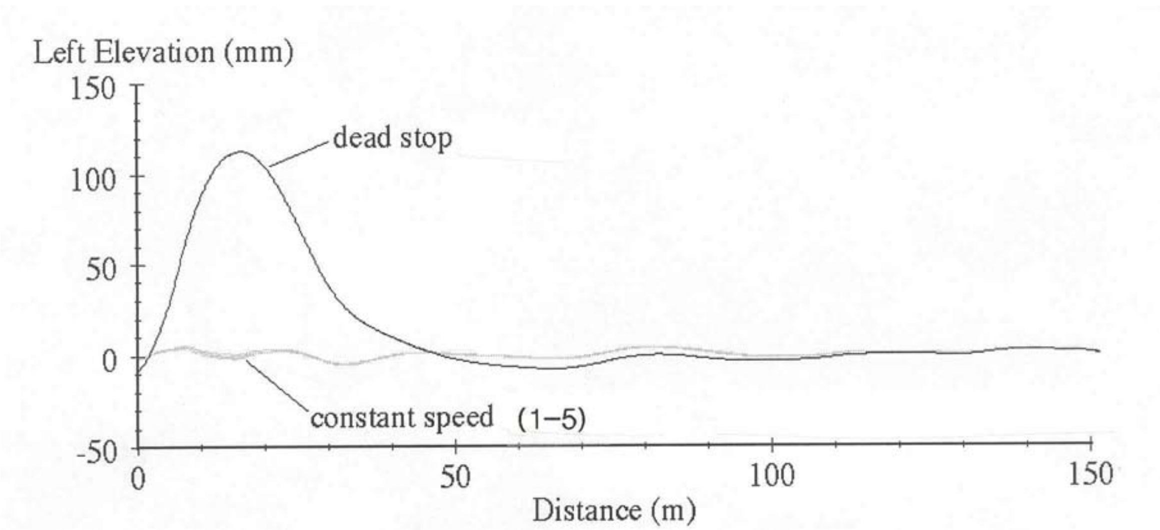


Figure 9. Effect of operating from a dead stop on profile data collected by a high-speed profiler (*7*).

El-Korchi (*9*) used data collected in Massachusetts for the FHWA lightweight profiler demonstration study to analyze the lead-in distance required by the filters in the different profilers that took part in the study. The study indicated the required lead-in distance varied according to the type of upper cut-off filter that was being used by the profiler.

## Lateral Positioning

Smoothness along different longitudinal paths of a lane may vary. The paths along which smoothness is to be measured for construction acceptance are specified by the highway agency in their smoothness specification. Usually profile data are collected along the two wheel paths, and the location of these wheel paths within a travel lane is specified in the smoothness specification.

The profiler driver must operate the profiler such that profile data are collected along these specified paths. The operator must ensure that the lateral sensor spacing of the profiler matches the spacing between the wheel paths that are specified in the smoothness specification. Consistent lateral positioning of the profiler is essential to obtaining repeatable measurements. When operating a lightweight profiler, a lateral guide can be used to maintain a consistent lateral position.

## MEASUREMENT ENVIRONMENT FACTORS AFFECTING PROFILE MEASUREMENTS

Moisture on the pavement surface as well as debris on the pavement surface can affect the profile data. The effect of each of these factors on profile data is described separately.

### Surface Moisture

Pavement profiling should not be performed on wet pavements. In a study of profiling with laser sensors Still and Jordan *(10)* reported that sensor dropout could occur if the surface texture is submerged in water. As suggested by that study, profiling should stop if the surface texture is submerged and may continue, "as soon as the surplus water on the road surface has drained away." Generally, a good guideline to follow is not to perform profiling if traffic is causing the surface water to splash or spray. Profiling can be performed on a damp pavement.

A study by Evans (*11*) showed the affect of moisture on the pavement on IRI values. In this study, profile data were collected on a pavement section when the section was wet, damp and dry using a profiler equipped with infrared sensors. When the pavement surface was wet, passing truck tires were throwing up water spray, but there was no standing water on the pavement. When the pavement was profiled under the damp condition, truck tires were not causing a spray. Figure 10 shows the IRI of the section under these three conditions, with seven profile runs being collected for each condition. As seen in this figure, profiling a pavement when it is wet results in the collection of erroneous data that cause high IRI values. The profile data that were collected under such conditions showed spikes in the data. The IRI values that were obtained on the damp and dry pavements were similar.

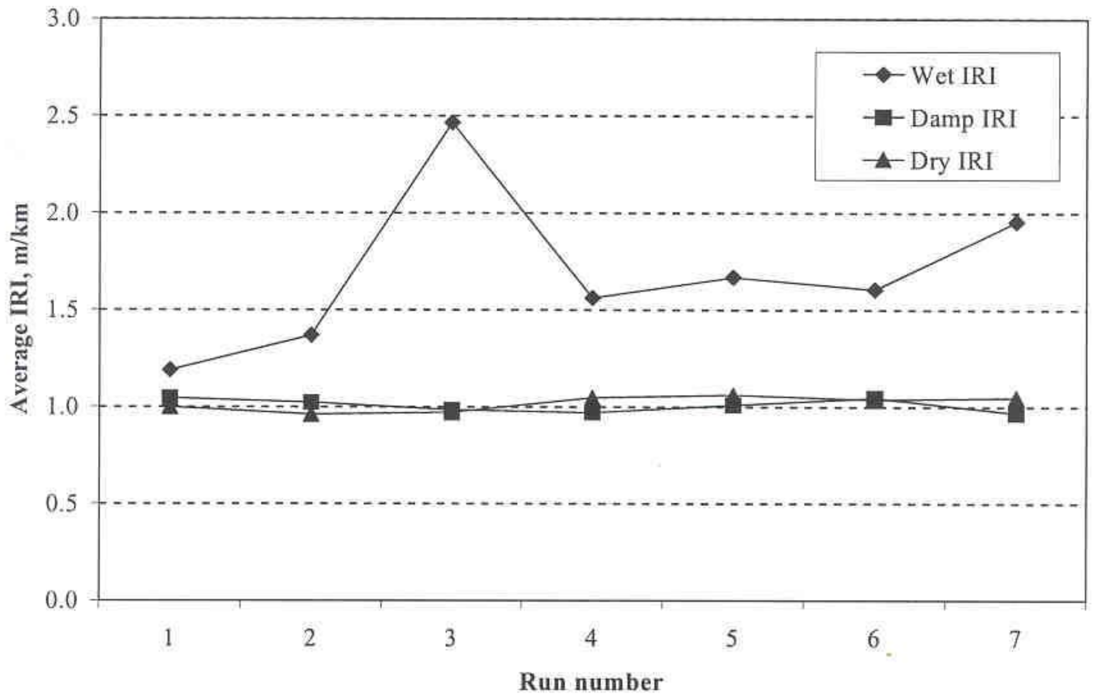


Figure 10. Effect of surface moisture on IRI (*11*).

## Surface Contaminants

Surface contaminants present on the road during profiling can cause errors in profile measurements. Surface contaminants that could be encountered when profiling new pavements for construction acceptance can include construction debris such as gravel or dirt. The pavement surface of new pavements that are being profiled for construction acceptance should be clean. If there is debris on the pavement surface, the surface should be broomed prior to performing profiler measurements. Some surface contaminants can have a substantially effect on the smoothness of a section.

Figure 11 shows a profile where a profile feature that was 18 mm (0.75 in) in height was added to the profile at a distance of 16.5 m (54 ft) and 33 m (108 ft) to simulate the effect of two surface contaminants. These two locations are clearly seen as two spikes in the profile. The IRI of the profile shown in figure 11 is 1.01 m/km (65 in/mi). If the two spikes were not there, the IRI of the pavement would be 0.83 m/km (52 in/mi). The two contaminants in the profile caused the IRI to increase by 22 percent. Some profilers may have a detection scheme in their software to eliminate such isolated spikes from being recorded. However, if surface contaminants are present throughout the roadway, such contaminants will be recorded as spikes.

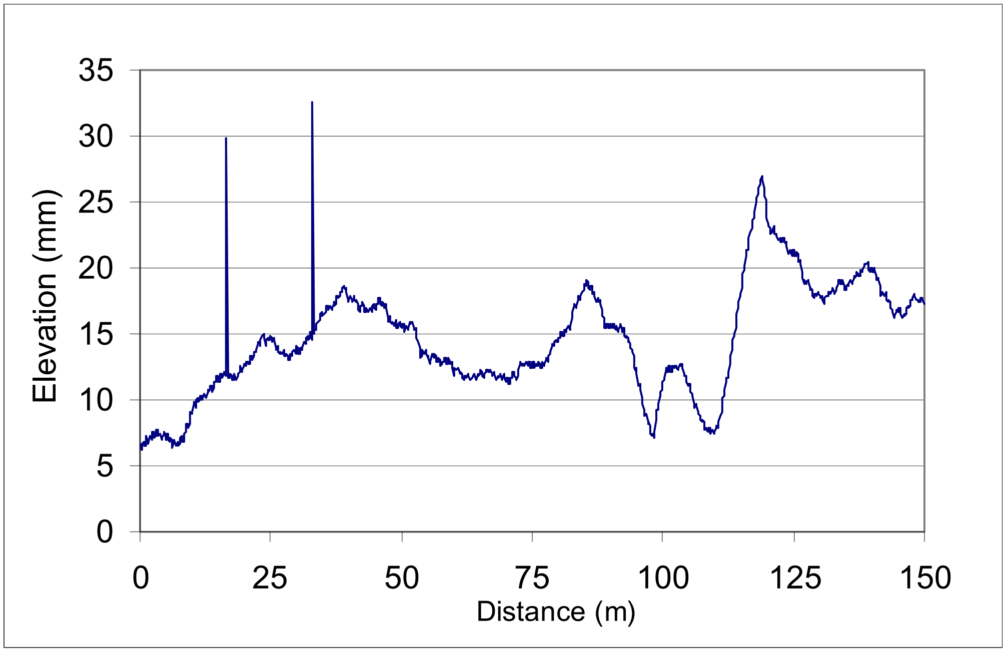


Figure 11. Profile obtained on a new AC pavement with two surface contaminants.

## OPERATIONAL CHECKS DURING DATA COLLECTION

The profile operator can ensure that accurate data are being collected during profiling by performing operational checks during the profile run. Some profilers have the ability to display height sensor readings as well as accelerometer readings, either graphically or numerically. If such a feature is present, the operator should be aware of the normal operating ranges for these measurements, and check the readings periodically to ensure that valid data are being collected. Some profilers may have a feature where a warning light or an audible beep is emitted if there are problems with the height sensors or accelerometers. Availability of such a feature in a profiler will ensure that erroneous data will not be collected. Most profilers have the ability to display the profile data that are being collected. The operator should check these displays periodically or at the end of the profile run to make sure the profiler is providing plausible output.

After completing a profile run, smoothness indices such as IRI or Ride Number can be generated from the profile data. After the completion of a profiler run, the operator should check these values to see if they are reasonable. If there are major problems with the height sensors, accelerometers or the data acquisition system, these will generally be reflected on the computed indices. If the profiler has the capability to view the collected profile in the field, a cursory check of the profile should be performed. Sometimes equipment problems can result in spikes in the profile. A spike in a profile is a localized deviation in the profile that is caused by one or two readings that are much higher than the surrounding readings. If the spikes are caused by surface contaminants, the surface should be cleaned, and the section should be profiled again.

## PROFILER VERIFICATION SITES

Verification sites can be established to periodically check the output of the profiler. These sites can be established close to the office. A minimum of two verification sites is recommended for profilers that are used for construction quality control, a smooth section with IRI less than 1.2 m/km (76 in/mile)), and a medium smooth section that has IRI between 1.6 and 2.0 m/km (101 and 127 in/mile). If the profiler is also used for network level data collection, an additional site that has a roughness between 2.5 and 3.0 m/km (158 and 190 in/mile) should be established. Elevation measurements at these sites should be obtained at the start of the year (after spring thaw) using a device such as a Dipstick, and the IRI values along the wheel path should be computed. These sites should be profiled by the profiler at regular intervals and the computed smoothness indices should be compared with the values obtained by the reference device. The time-sequence roughness values that are being obtained by the profiler should be examined to check if they are consistent. In addition, the profiles obtained by the device should also be compared with previous profiles. If such a procedure is followed by the agency, problems with the equipment can be detected easily.

## CONCLUSIONS

Many highway agencies are now starting to use inertial profilers to collect profile data on new and rehabilitated pavements for construction acceptance. Acceptance of the pavement as well as bonus and penalties are based on a smoothness index such as IRI that is computed from the profile data. Therefore, it is very important that the profile data that are collected by inertial profilers be error free. This can be ensured by using the following procedures when collecting profile data:

- Calibrate height sensor(s), accelerometer(s), and distance measuring systems following manufacturers' recommended procedures.
- Clean lenses in sensors and check tire pressure before profiling.
- Perform daily checks on profiler – bounce test and static height sensor check.
- Set sensor spacing to spacing specified in smoothness specification.
- Collect profile data along path specified in smoothness specification. Follow consistent path without lateral wander during profiling.
- Do not collect profile data outside the speed range that is specified for the profiler.
- Maintain a constant speed during data collection. Do not accelerate or decelerate during data collection. If you stop the profiler in a middle of a profiling run, discard the data for that run.
- Have an adequate lead-in distance prior to test section to initialize data collection filters and come up to speed. Strictly follow manufacturers guidelines.
- Initiate data collection at specified location. If the profiler is equipped with an automated method to initiate data collection (e.g., photocell) use it to initiate data collection.
- Do not profile wet pavements.
- Do not collect data on pavements that have surface contaminants (e.g., gravel, construction debris).
- Evaluate collected profile data for presence of spikes.

## REFERENCES


1. Kulakowski, B.T. and J.C. Wambold, "Development of Procedures for the Calibration of Profilographs," *Report FHWA-RD-89-110*, Pennsylvania Transportation Institute, State College, PA, 1989.
2. Spangler, E. B. and Kelley, W. J., " GMR Road Profilometer–A Method for Measuring Road Profile," *Research Publication GMR-452*, General Motor Research Laboratory, Warren, Michigan, 1964.
3. Sayers, M.W. and Karamihas, S.M., The Little Book of Profiling: Basic Information about Measuring and Interpreting Road Profiles, University of Michigan Transportation Research Institute, Ann Arbor, Michigan, 1998.
4. American Society of Testing and Materials, Road and Paving Materials: Vehicle Pavement Systems, Volume 4.03, 1999.
5. Perera, R.W., Kohn, S.D., and Rada, G.R.J., "LTPP Manual for Profile Measurements: Operational Field Guidelines, Version 3.1," Federal Highway Administration, Washington, D.C., 1999.
6. LMI Selcom, User's Manual, Optocator.
7. Karamihas, S.M., Gillespie, T.D., Perera, R.W. and Kohn, S.D., "Guidelines for Longitudinal Pavement Profile Measurement," NCHRP Report 434, Transportation Research Board, Washington, D.C., 1999.
8. Gillespie, T.D, Karamihas, S.M., Perera, R.W. and Kohn, S.D., "Operational Guidelines for Longitudinal Pavement Profile Measurement," *Research Result Digest 244*, Transportation Research Board, Washington, D.C., 1999.
9. El-Korchi, T., "Correlation Study of Ride Quality Assessment Using Pavement Profiling Devices," Research Report CEE 00-0122, Worcester Polytechnic Institute, Worcester, Massachusetts, 2000.
10. Still, B.P. and P.G. Jordan, "Evaluation of the TRRL High-Speed Profilometer," Laboratory Report 922, Transport and Road Research Laboratory, Crowthorne, Berks, United Kingdom, 1980.
11. Evans, L.D. and Ellahan, A., "LTPP Profile Variability," Report FHWA-RD-00-113, Federal Highway Administration, Washington, D.C., 2000.