Measuring and Analyzing Pavement Texture

Concrete Pavement Surface Characteristics Program

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Introduction

Pavement texture is defined by the irregularities on a pavement surface that deviate from an ideal, perfectly flat surface. As shown in Figure 1, the World Road Association (PIARC) has established standard categories of texture, classified by wavelength. These categories include microtexture (wavelengths up to 0.5 mm), macrotexture (0.5 to 50 mm), megatexture (50 to 500 mm), and roughness (wavelengths larger than 500 mm).

Texture influences many aspects of road safety and comfort, including friction, smoothness, splash and spray, and rolling resistance. Figure 1 also illustrates the ranges of texture that influence these pavement surface characteristics, with a positive influence shown in green and deleterious effect shown in red. The focus of this technical brief is on techniques to measure and analyze texture, particularly those that influence tire-pavement noise and friction.

In modern concrete pavement construction, texture is deliberately imparted in a reasonably-controlled manner. The nominal geometry of the texture is typically prescribed, either directly or indirectly. For example, as illustrated in Figure 2, the spacing and depth of the directional striations produced by tining are often described in a specification. Diamond-ground textures will be defined in large part by the geometry of the grinding head (blade widths and spacers). Even the texture of a drag surface will be defined to some degree by the specific mechanical means used to impart these surfaces.

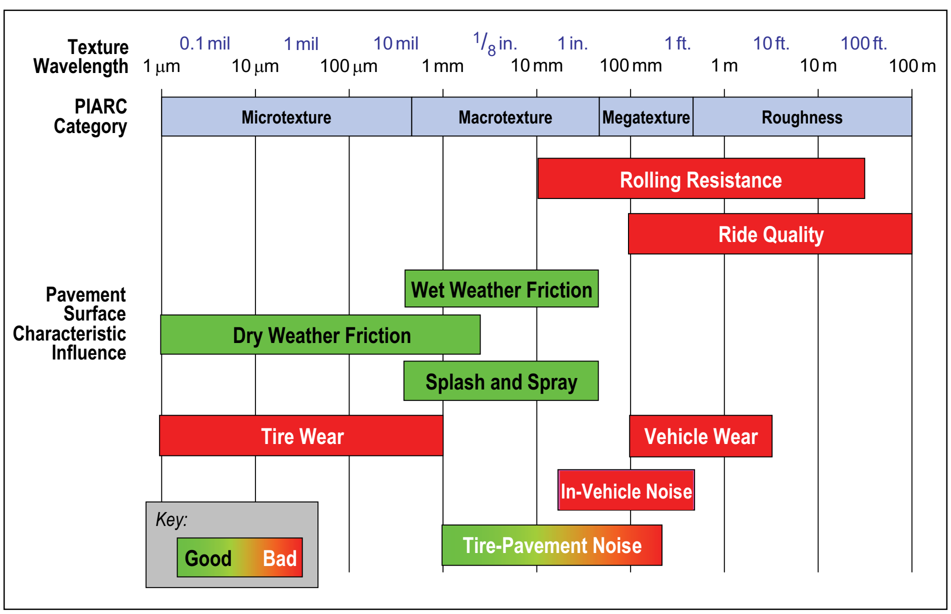

Figure 1. World Road Association (PIARC) texture definitions and their influence on pavement surface characteristics

While it would be ideal for the as-constructed texture to match the as-designed (nominal) geometry, this is not usually the case. Numerous factors affect the final texture, including variability in materials and construction technique. This is illustrated in Figure 3, which shows variability of pavement texture on two areas of a project that were constructed within minutes of each other. In addition to initial variability, texture changes over time due to both traffic and the environment.

With texture affecting so many different surface characteristics, it is an ideal parameter to evaluate as part of construction quality control. Furthermore, because texture is simply geometry, it is a fundamental aspect of a pavement surface to measure. This technical brief discusses pavement texture measurement and, specifically, the methods used in the Concrete Pavement Surface Characteristics Program (CPSCP). (It also describes the methods and metrics used to quantify texture.)

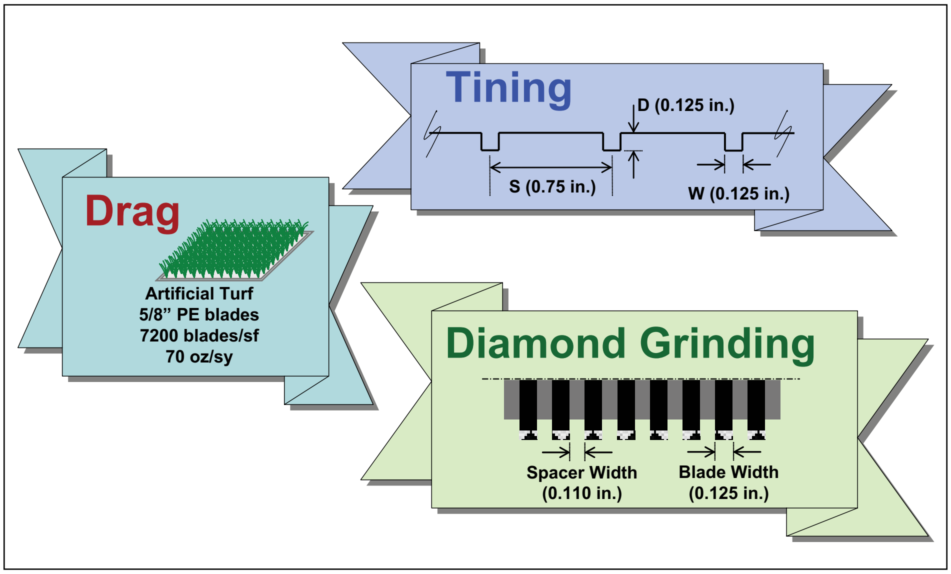

Figure 2. Typical texture specification

Figure 3. Material and construction variability affect the as-constructed texture

Measuring Texture

Laser-based profilometry is the most commonly used technique to collect pavement texture data. Various standards have been developed to describe the requisite equipment in such a way that is relevant to the type of texture to be measured. Of these, ISO 13473 is the most commonly cited. While other texture measurement methods have been advanced, they often possess technical or practical limitations. Laser-based texture profilometry uses technology that is similar to road profilers that evaluate pavement smoothness. However, when measuring texture, a greater degree of precision and accuracy is needed with respect to small features that are normally filtered out when evaluating road roughness.

Most profilers in use today measure texture using a single-point laser, which results in a two-dimensional (2D) texture profile with distance along the pavement surface as one dimension and the texture elevation as the second. Concrete pavement texture is complex, though: it is anisotropic, meaning that the texture varies depending on the direction of the measurement (longitudinal or transverse). Therefore, measuring a 2D profile fails to completely describe characteristics of the texture that are important to many surface characteristics. In addition, measuring with a single-point laser can introduce artifacts in the measurement that distort the profile and, therefore, introduce error in predicting the surface characteristic of interest.

To overcome the limitation of using a spot sensor, a line laser can be used. Traditionally, line lasers are found in machine vision applications. In recent years, vendors of these sensors have worked with the highway industry to develop variants of the sensors that are suitable for texture profile applications.

Figure 4 illustrates the measurement principle of a line laser. Measuring with a line laser results in a three-dimensional (3D) texture profile with distance along the pavement surface as one dimension, distance along the laser line as the second dimension, and texture elevation as the third dimension.

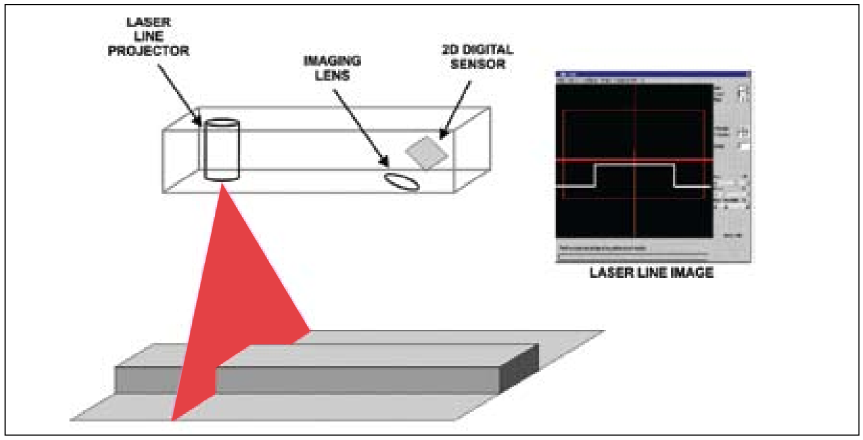

Figure 4. Measurement principle of the LMI Technologies RoLine line laser height sensor

RoboTex

A line laser sensor alone cannot measure pavement texture properly. A platform with a means to mobilize the sensor is required. In 2005, a prototype of an innovative system for texture measurement was developed: a robotic-based texture measurement system (RoboTex). As shown in Figure 5, the system is built on a robotic chassis for remote control of the measurement platform speed and travel direction.

RoboTex includes customized software that simultaneously collects and stores data from a number of sensors. As illustrated in Figure 5, the components include:

- Line laser sensor – for height data
- Accelerometer – to establish an inertial reference elevation
- Wheel encoder – to determine the precise position of the robot
- Global positioning system (GPS) – to establish a global position of the robot for reference
- Time – to determine speed and for global reference
- Digital imaging system – for a visual record of the surface

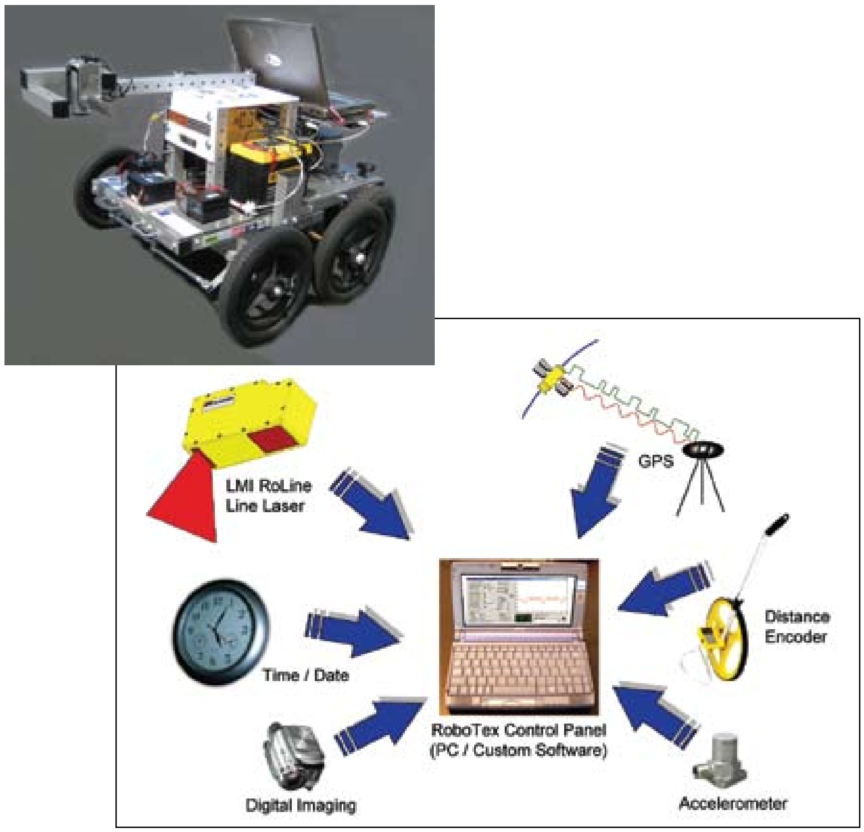

Figure 5. RoboTex (above) and schematic of RoboTex components (below)

This concept device provides a better tradeoff between resolution and efficiency in texture data collection. RoboTex is capable of sampling 100 or more texture elevation points across a 100 mm wide laser line at 1000 Hz as it travels down the road under its own power at about 0.5 m/s. This yields a pavement texture measurement with a spatial resolution of about 0.4 mm^2 and a height resolution of 0.01 mm. More importantly, the result is a 3D texture profile along a 100 mm wide swath of pavement surface, as illustrated in Figure 6.

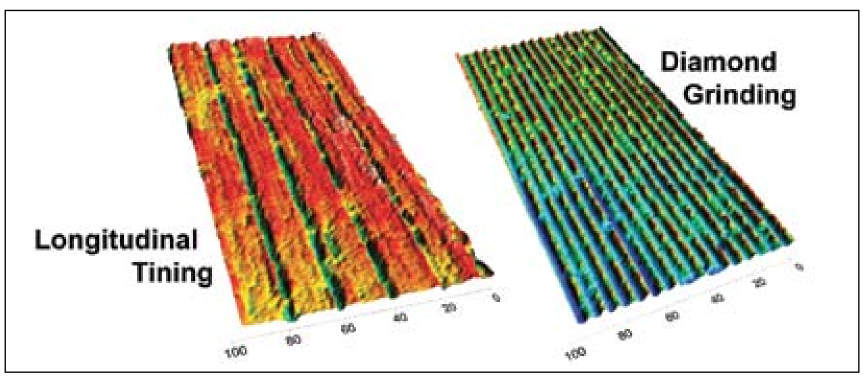

Figure 6. Sample RoboTex data from concrete pavement textures

Geometric Texture Metrics

While illustrations of the measurements, as shown in Figure 6, are useful, they do not quantify texture and a multitude of ways to characterize texture exist. The selection of a proper metric begins with an understanding of the fundamental mechanisms that describe the surface characteristics of interest. Ideally, a texture metric describes the texture in a way that relates its interaction with a tire.

Quite often, texture depth is used as a texture metric. However, texture depth can be calculated in numerous ways. To illustrate this, refer to a short (100 mm) sample of tined concrete pavement texture, as illustrated in Figure 7.

A straightforward way to calculate texture depth is to calculate an average (rectified) deviation of the texture from the mean depth. This is illustrated on the top of Figure 8, where the sum of the shaded areas both above and below the mean profile elevation is divided by the length of the profile (100 mm). The result is in an average texture depth (R_a) of 0.42 mm. Alternatively, the texture profile shown in Figure 7 can be squared, as illustrated on the bottom of Figure 8. Taking this area, dividing by the length of the profile, and then taking the square root, results in the root-mean-square (RMS) texture depth (R_q). In this example, the RMS is 0.63 mm. Mathematically, these calculations are made as follows using measured texture data:

$$R_a = \frac{\sum_{n=1}^{N} |z_n|}{N} \quad \text{and} \quad R_q = \sqrt{\frac{\sum_{n=1}^{N} z_n^2}{N}}$$

where:

N = number of measured samples of texture profile

z_n = texture profile elevation data (starting with n=1, and ending with n=N) after detrending

One disadvantage of most texture-depth

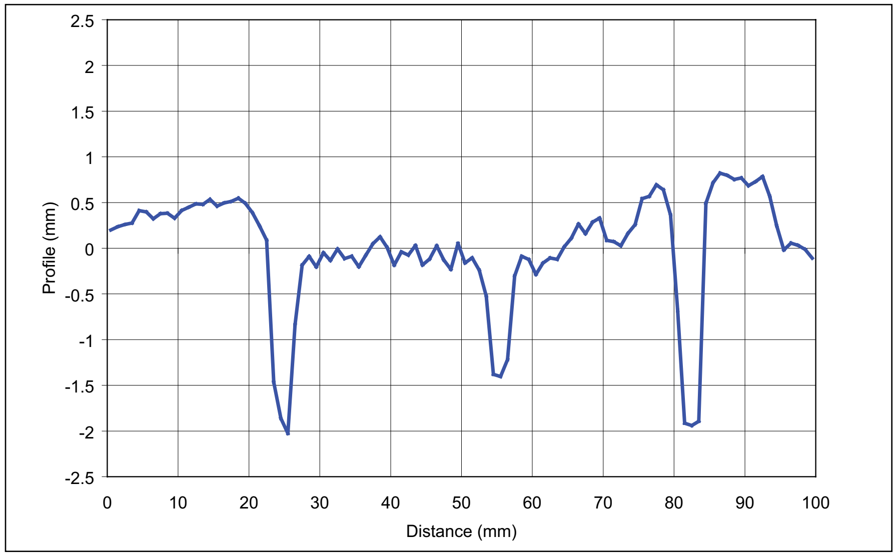

Figure 7. Sample texture profile

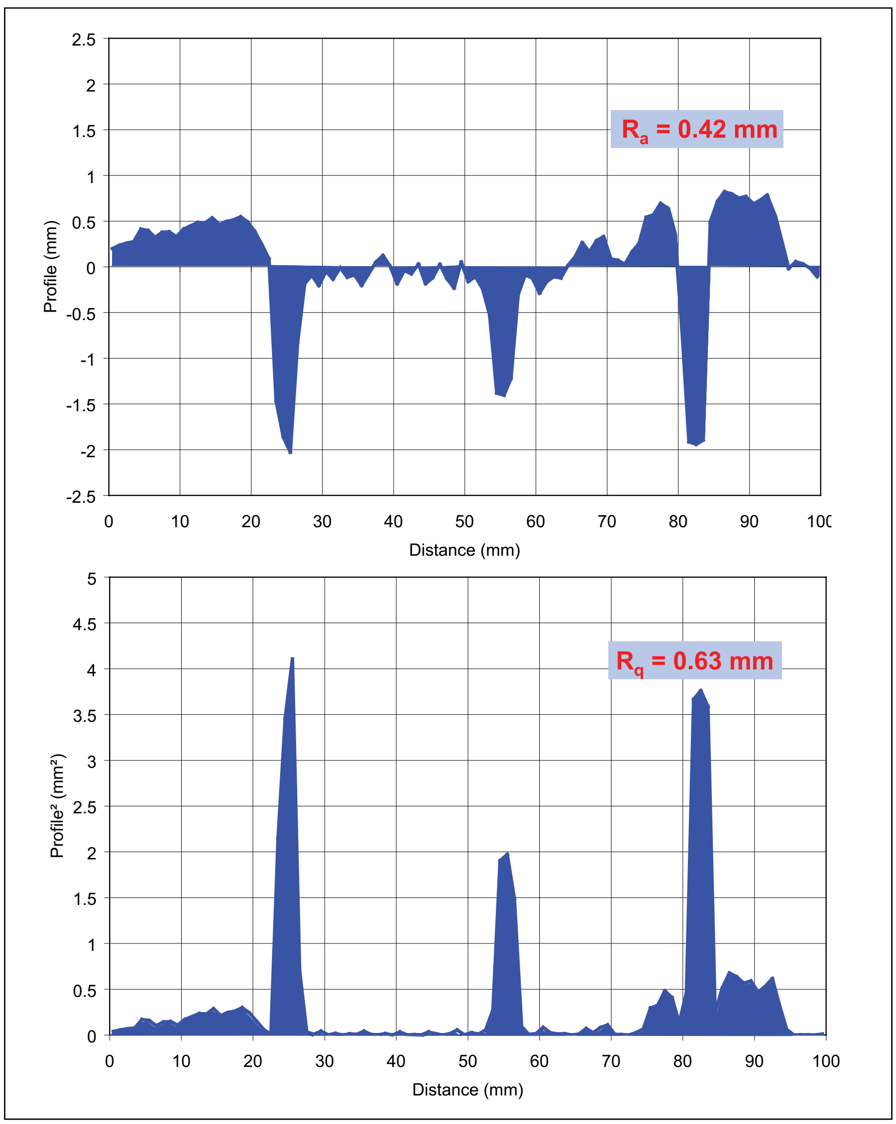

Figure 8. Calculation of average texture height, Ra (top), and RMS texture height, Rq (bottom)

metrics is the lack of sensitivity to directionality of the texture. For example, the same R_a and R_q values are calculated for the texture profile in Figure 7, even if the profile is "flipped over" (upside down). In the flipped-over case, the tined grooves become sharp spikes and, clearly, a tire would interact with this profile very differently than the right-side-up profile. To help overcome this limitation, a directionality metric, termed texture skewness (R_{sk}), is calculated as follows:

$$R_{sk} = \frac{\sum_{n=1}^{N} z_n^3}{R_q^3 N}$$

For textures like that shown in Figure 7, the skew is negative (in this example, -1.7). If the profile is flipped over, the texture has a positive skew.

Historically, pavement texture depth has been measured using the volumetric ("sand") patch technique and reported as a mean texture depth (MTD). The test involves carefully spreading a known volume of small glass beads into a circle on the pavement surface and the MTD is simply the volume of beads divided by the area of the circle. As laser-based profilers began to be used, the mean profile depth (MPD) metric was developed as a means to estimate the MTD.

As shown in Figure 9, calculating MPD involves dividing the 100 mm texture profile into two 50 mm segment halves. A peak profile point in each segment half is determined, then averaged, and, then the mean profile elevation (in this case, zero) is subtracted. The result in this example is 0.69 mm. Note that the currently-proposed revision to the ISO 13473-1 specification refers to the calculation within a 100 mm sample as a mean segment depth (MSD), so, the MPD is then an average of numerous (minimum of five) MSD values.

Functional Texture Metrics

While geometric metrics, such as depth and skewness, are intuitive and straightforward to calculate, they do not describe the interaction of a tire and the pavement texture by themselves. Functional texture metrics are more useful in this regard. ISO specification 13565-2 describes a process of transforming a texture profile into a profile-bearing ratio curve. As illustrated in Figure 10, this begins with the recognition of three distinct "regions" of texture.

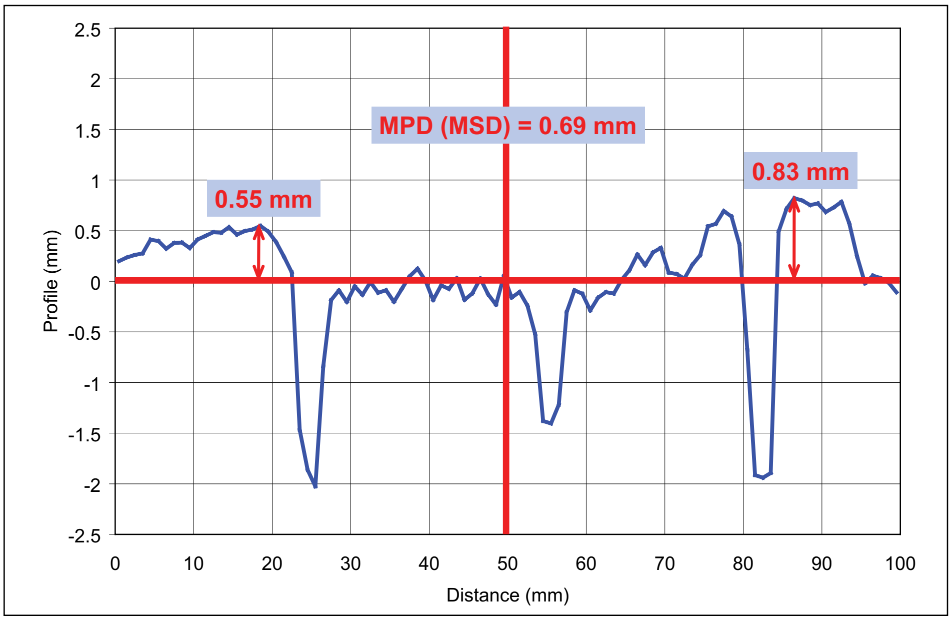

Figure 9. Calculation of mean profile (mean segment) depth

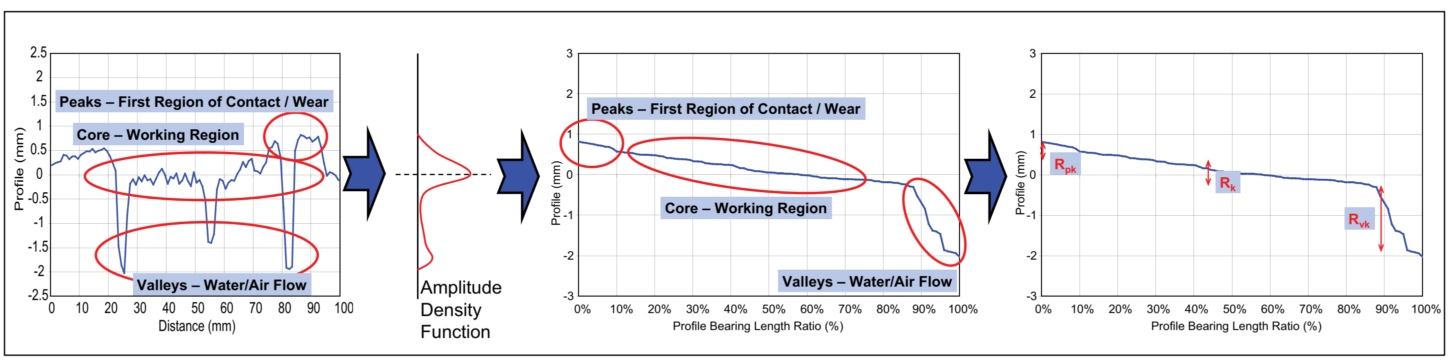

Figure 10. Calculation of profile-bearing ratio from a texture profile

The peaks are the first to be contacted by a tire, and the most rapid to wear. The second region is the core, where most of the texture typically lies, and therefore describes the longevity of the texture. The lowest regions are termed valleys, and are where air and water that are not necessarily in contact with the tire can possibly reside. Calculation of the heights of these three regions first involves converting the texture profile to a profile-bearing length ratio (a type of cumulative distribution of texture elevations). From this, various chord and area calculations derive the parameters of reduced peak height (R_{pk}), core roughness depth (R_k), and reduced valley depth (R_{vk}).

Spectral Texture Metrics

Spectral analyses of pavement textures are used to identify the presence or significance of various repeating features. To illustrate this, Figure 11 shows a spectral analysis of the same tined pavement shown in Figure 7. (More on the technique used for this type of analysis is included in ISO 13473-4.)

From this plot, a characteristic peak at 25 mm is visible, which corresponds to the tine spacing. Other less-obvious characteristics of the texture can sometimes be derived from spectral analyses, particularly when the texture wavelength is plotted in narrow bands (as opposed to third-octave, illustrated here). Furthermore, there is often a correlation between some pavement surface characteristics and the texture content within select spatial frequency bands (or texture wavelengths). Also note that, in Figure 11, a transformation of the texture elevation was made to a texture level using a decibel scale and a reference RMS texture of 1 µm. (Don't confuse this with the decibel scale that is used for noise measurement and reporting.)

Bridging Filter

Ideally, the texture metrics that are calculated should correlate well to the pavement surface characteristics of interest. However, this is not always the case. Tire-pavement noise, in particular, is a difficult response to predict given its complexity. One technique that has successfully improved this correlation is the application of a bridging (or envelopment) filter. The filter is applied to texture profiles prior to calculating key texture metrics, most notably spectral analysis.

The specifics of the bridging filter are governed by the response of interest. For example, in the case of tire-pavement noise, the filter geometry is on the same scale as that of the tire tread. As illustrated in Figure 12, the filter simulates how a tire tread would impregnate the texture. The elevation of the filtered profile is calculated as a balance of the downward force on the tire and the upward reaction due to the elasticity of the tire. This occurs when an equivalent uniform tire rubber displacement (e.g., 1 mm) is achieved. At this point of equilibrium, a single filtered elevation is calculated and stored as the bridged elevation and the process is repeated again after incrementally moving the filter forward. Mathematically, the filtering process can be further simplified by sorting the texture profile elevations. This is illustrated in Figure 13.

Conclusions

Texture is a vitally important pavement property because it relates to most of what defines functional performance vis-à-vis pavement surface characteristics. It has been shown that measuring the texture of concrete pavements in an accurate and relevant manner requires 3D data, which, in the CPSCP, was collected using an innovative device called RoboTex. The data from RoboTex was used to calculate numerous texture metrics, including those described herein. As a result, the as-constructed texture could be related to surface characteristics, such as tire-pavement noise and friction, and better practices could be developed for the design and construction of concrete pavement surfaces.

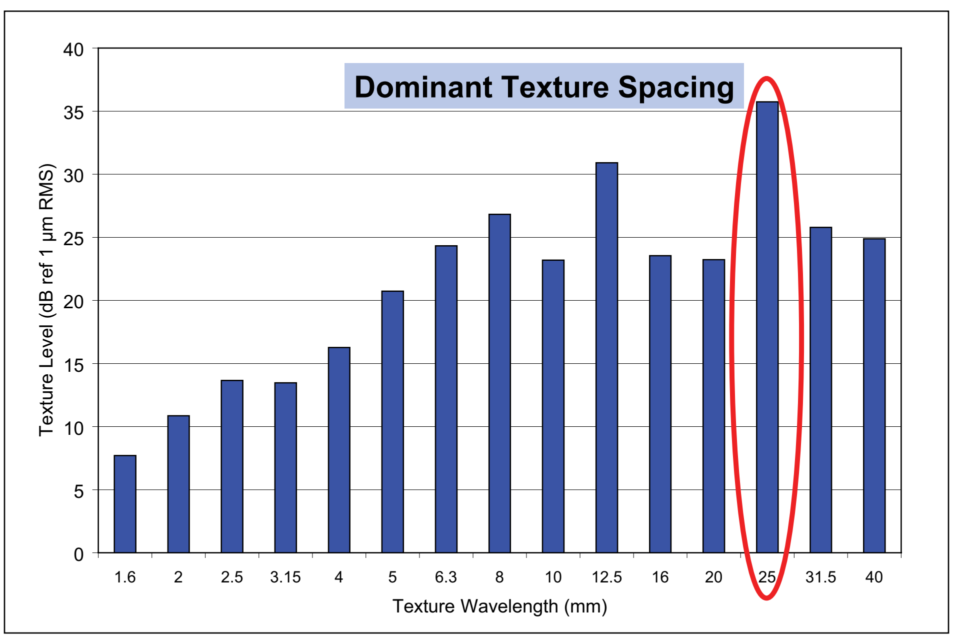

Figure 11. Spectral analysis of texture profile

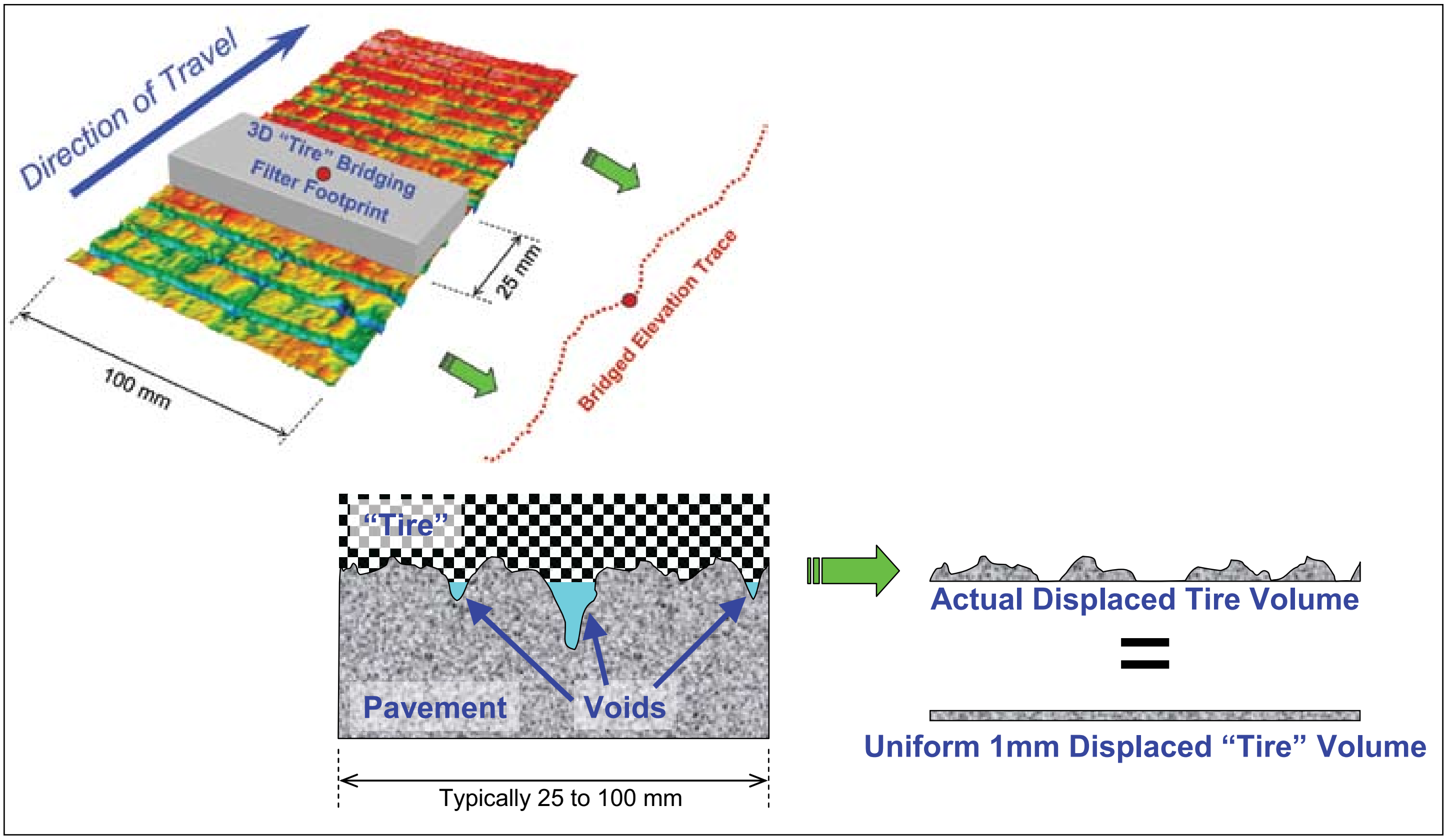

Figure 12. Principles of tire tread bridging filter

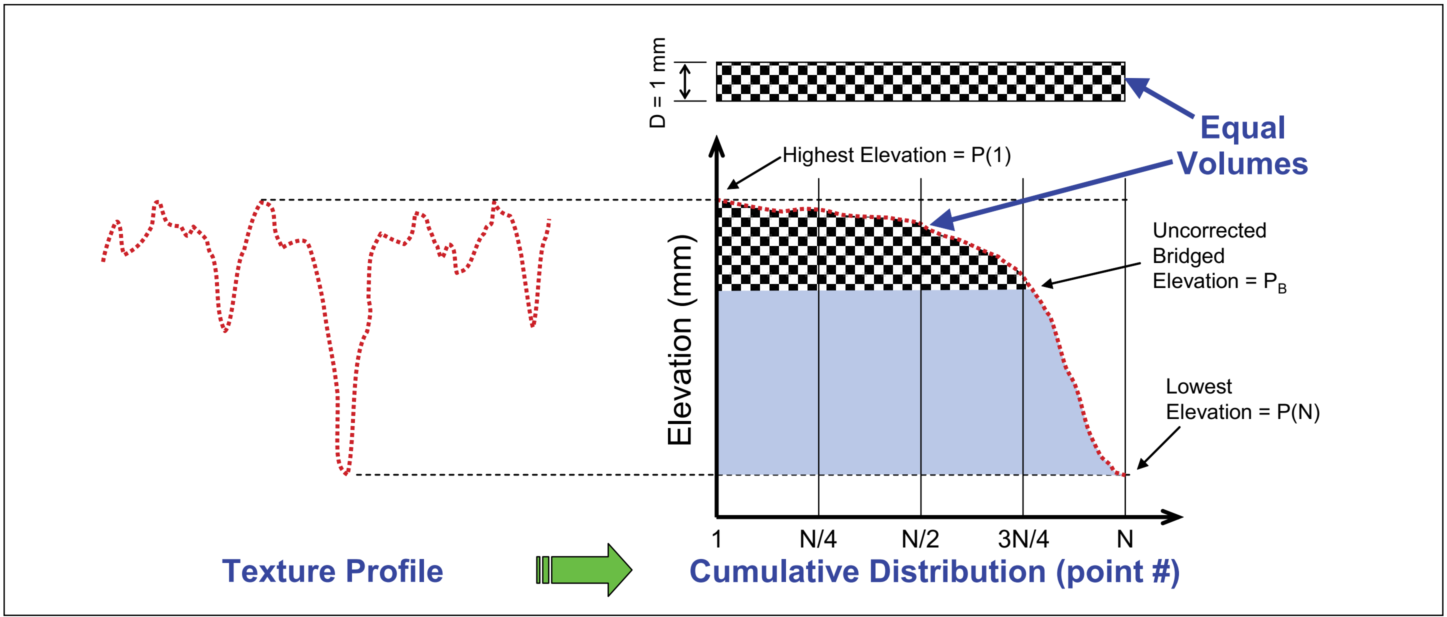

Figure 13. Calculation of bridged elevations using tire tread bridging filter

For More Information

- ASME, "Surface Texture (Surface Roughness, Waviness, and Lay)," An American National Standard, ASME B46.1-2009.
- ASTM, "Standard Test Method for Calculating Pavement Macrotexture Mean Profile Depth," Standard E 1845-96.
- ASTM, "Standard Test Method for Measuring Pavement Macrotexture Depth using a Volumetric Technique," Standard E 965-01.
- ISO, "Characterization of pavement texture by use of surface profiles – Part 1: Determination of Mean Profile Depth," ISO/TC 43/SC 1/ N 1xx, ISO/WD 13473-1, 2009.
- ISO, "Characterization of pavement texture by use of surface profiles – Part 2: Terminology and basic requirements related to pavement texture profile analysis," ISO 13473-2: 2002.
- ISO, "Characterization of pavement texture by use of surface profiles – Part 3: Specification and classification of profilometers," ISO 13473-3: 2002.
- ISO, "Characterization of pavement texture by use of surface profiles – Part 4: Spectral analysis of surface profiles," ISO/TS 13473-4: 2008.
- ISO, "Geometrical Product Specifications (GPS) – Surface texture: Profile method; Surfaces having stratified functional properties – Part 2: Height characterization using the linear material ratio curve," ISO 13565-2: 1996.
- Robert O. Rasmussen, et al., "The Little Book of Quieter Pavements," Report FHWA-IF-08-004, USDOT Federal Highway Administration, 2007.
- Steven Karamihas, "Critical Profiler Accuracy Requirements," University of Michigan Research Report UMTRI-2005-24, 2005.

About the Concrete Pavement Surface Characteristics Program

In December 2004, a coalition was formed between the National Concrete Pavement Technology Center (National CP Tech Center), the Federal Highway Administration (FHWA), the American Concrete Pavement Association (ACPA), and the International Grooving and Grinding Association (IGGA).

The mission of the program was to help optimize concrete pavement surface characteristics—more specifically, it was to find innovative solutions to make concrete pavements quieter without compromising safety, durability, or cost effectiveness.

The current program is now operating under Pooled Fund TPF-5(139) with the additional support of state DOTs, including California, Iowa, Minnesota, New York, Texas, Washington, and Wisconsin.

Recent focus is on identifying specific guidance to properly design and construct quieter concrete pavements. Innovative concrete pavement surfaces are also being evaluated to assess their potential as viable solutions.

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