What Makes a Quieter Concrete Pavement?

Concrete Pavement Surface Characteristics Program

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Introduction

Concrete pavements can be designed and constructed to be as quiet as any other conventional pavement type in use today. This Tech Brief provides an overview of how this can be done—and done consistently.

Constructing a quieter concrete pavement requires the texture to have certain fundamental characteristics. While innovative equipment and techniques have shown the promise of quieter pavements in the future, quieter concrete pavements are routinely built today all across the country using standard nominal concrete pavement textures: diamond grinding, drag, longitudinal tining, and even transverse tining *(1)*.

Data have proven that quieter concrete pavements do not sacrifice safety, because there isn't a relationship between friction and noise. As illustrated in Figure 1, quieter surfaces vary in friction in the same way that louder surfaces do. Tire-pavement noise is shown in figure 1 as measured with on-board sound intensity (OBSI) *(2)* and is compared to friction values, which are skid numbers (a metric commonly used by state highway agencies) *(3)*.

Quieter concrete pavements can also be durable and cost effective to build.

One reason why not all concrete pavements are quiet is the lack of a collective understanding about what makes them quiet. To address this problem in recent years, the National Concrete Pavement Technology Center (National CP Tech Center) has amassed the largest database, to date, of concrete pavement surface characteristics. The database includes noise, texture, and friction measurements.

Nearly 1,500 test sections throughout North America and Europe have been evaluated (4). From this effort, an understanding of the fundamental surface properties that affect noise has

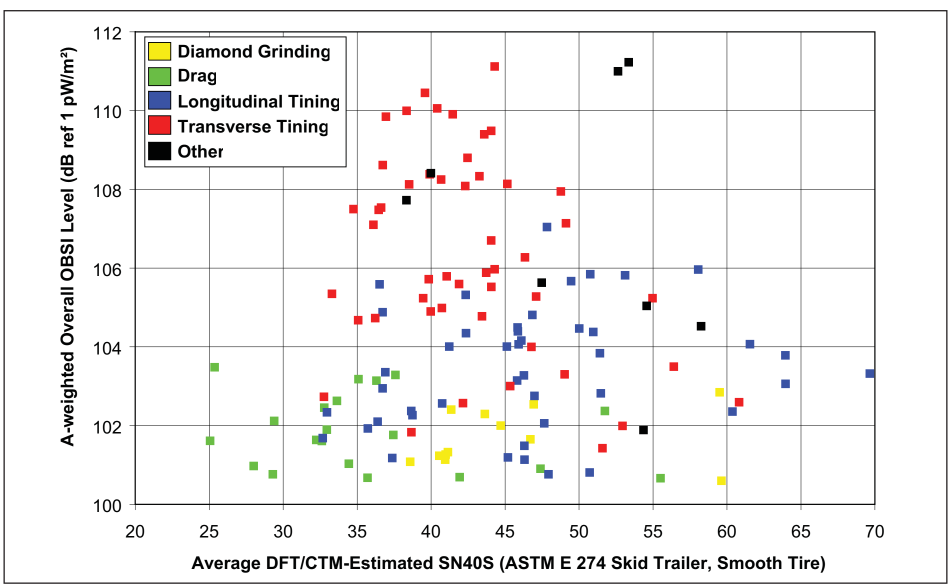

Figure 1. Tire-pavement noise levels versus pavement friction levels for various concrete pavements.

emerged. Based on this knowledge, better practices have been defined.

Both the "best" and the "worst" of virtually every nominal concrete pavement texture in use today has been catalogued as part of the evaluation. With so many measurements, distributions were developed showing what noise characteristics are possible for each nominal texture type.

The distributions that have been found are due to differences in design, construction, age, climate, traffic, and many other factors.

With respect to tire-pavement noise, Figure 2 illustrates the sheer range of levels that have been measured on pavements to date. The pavements are broken down by nominal texture type and shown as normalized distributions of the noise levels evaluated using OBSI (2).

Note that the pavements measured under the Concrete Pavement Surface Characteristics Program (CPSCP) have a bias toward those earlier in life, because one of the program goals is to link the measurements to construction factors generally only available for younger sections.

Another small, but important, source of the variability in these distributions is the differences between operators who measure OBSI. (This effect has been and continues to be evaluated independent of this study (5, 6).)

Based on the work conducted to date, an A-weighted tire-pavement noise level of approximately 101 dB (ref 1 pW/m²), measured using OBSI at 60 mph, appears to be a reasonable target threshold for new concrete pavements (7, 8).

As Figure 2 shows:

- A majority of the conventional diamond ground surfaces that were measured meet the goal.
- About a third of the drag textures also meet the goal.
- About a quarter of the longitudinally tined surfaces meet the goal.
- A small but important fraction of transversely tined surfaces meet the goal; and, for those that did, the nominal tine spacings are all at or less than 0.5 in. (12.5 mm).

The data show that all conventional nominal textures have the potential to be constructed as quieter concrete surfaces, although some are more likely to be quieter than others.

Note that these results do not include important innovations, such as pervious concrete or the next-generation concrete surface, developed by the American Concrete Pavement Association (ACPA) and the International Grooving and Grinding Association (IGGA).

While selection of the nominal texture might be the first logical step toward achieving the goal of a quieter pavement, this is not the sole intent of the study. Instead, better practices are necessary to help owner-agencies and/or contractors achieve the quietest surface within any given nominal texture. Developing better practices requires tapping into the combined experience of both concrete paving contractors and paving equipment manufacturers.

Summary of Better Practices

1. **Recognize** which properties of a pavement surface make it quiet (and which make it loud).
2. **Design** the pavement surface to avoid adverse properties.
3. **Construct** the pavement surface in a manner that is both consistent and cost effective.

The first practice, recognition, has been addressed in large part under the CPSCP and through the results of numerous other studies *(8, 9, 10)*. To help with recognition, some of the most relevant Concrete Pavement Surface Properties that Affect Tire-Pavement Noise are summarized and highlighted on page 3.

Better practices to improve surface properties and reduce tire-pavement noise are really about establishing a higher order of control over the texture and other surface properties. Innovation can be helpful in achieving this goal, particularly with feedback systems that are relevant to how the texture is imparted (either in fresh concrete or through diamond grinding). The feedback can, at the very least, instill a renewed awareness of the impact

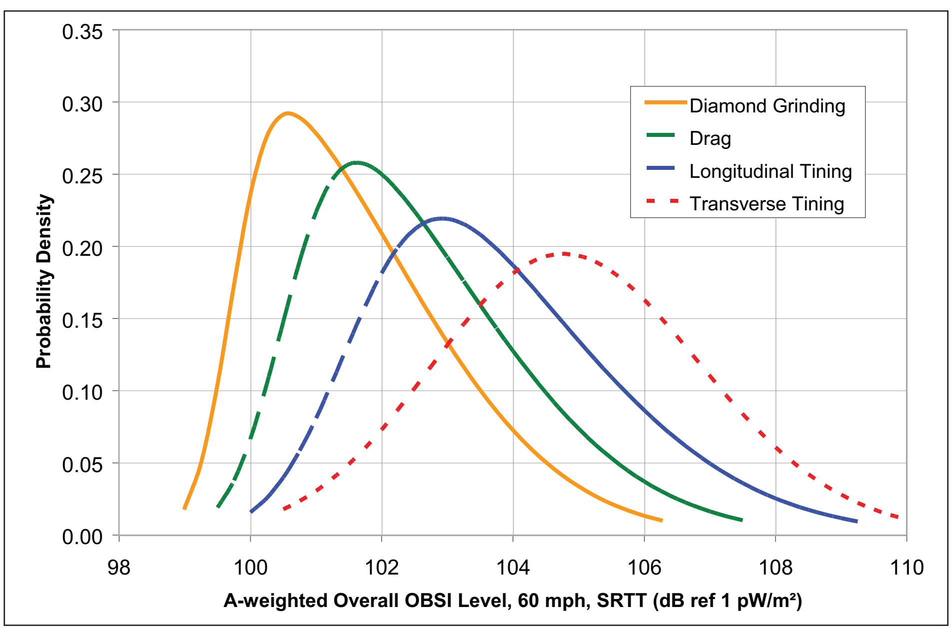

Figure 2. Normalized distributions of OBSI noise levels for conventional concrete pavement textures.

that some of the subtle operational characteristics can have on the texture as constructed.

Predictable tire-pavement noise levels are not about how the texture is imparted as much as they are about the recognition and management of the sources of variability. Regarding the concrete, noise levels have to do with the fact that the contractors are imparting texture into a material with inherent variability in both stiffness and plasticity.

Concrete changes from batch-to-batch, and it changes within a batch. The wind and the sun play a major role, as does the timing of the concrete mixing, transport, placement, and the texturing and curing (the latter being important for acoustical durability). Because of these ever-changing parameters, equipment innovations, such as vibration and motion monitoring and continuous texture measurements, are being developed.

The highlighted Summary of Better Practices to Reduce Tire-Pavement Noise on page 4 includes some of the better practices *(1)*. The summary can serve as another helpful reference in understanding the numerous issues that affect tire-pavement noise.

These and other better practices can be adopted to reduce tire-pavement noise. Many of these better practices also improve smoothness, improve durability, and, even, reduce costs.

Controlling Concrete Pavement Surface Texture

The methods and practices for imparting and controlling surface textures used today are often ineffective in meeting a nominal texture pattern, much less meeting it in a consistent manner. Even if tining, drag, and diamond grinding are all done with the best equipment, other variables, such as those illustrated in Figure 3, ultimately affect the final texture.

Figure 4 illustrates this further. The three sets of four photographs in Figure 4 show how variability in the as-constructed texture can lead, in turn, to very different tire-pavement noise (OBSI) levels.

The photographs were taken on one of the CPSCP test sites on US 30 in Iowa *(8)*. In each set of four photographs, the different appearance of the texture between the louder and quieter areas can be seen. For those sections that are louder, one or more of the surface texture characteristics noted in the first list in the box below can be observed.

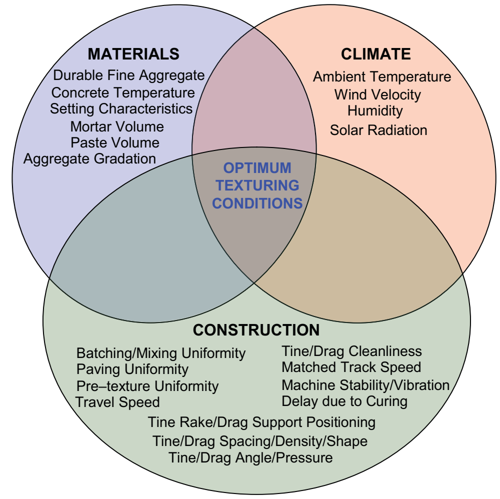

Figure 3. Variables affecting texture and the concept of an optimum texture window

Concrete Pavement Surface Properties that Affect Tire-Pavement Noise

Surface texture (bumps and dips)

- Avoid (flatten) texture that repeats itself at intervals of 1 in. (25 mm) or larger.
- Avoid extremely smooth (e.g., floated or polished) surfaces; instead, some fine texture (that is on the scale of 1/8 to 1/4 inch – 3 to 6 mm) should be provided.
- Texture should be "negatively" oriented, meaning that any "deep" texture should point down (e.g., grooves) rather than up (e.g., fins).
- Striations or "grooves" should, if possible, be oriented in the longitudinal direction, as opposed to the transverse direction.
- If grooves are oriented in the transverse direction, they should be closely spaced and randomized whenever possible. The depth of the grooves can be important in some cases, particularly if material that is displaced is re-deposited on the lands (areas between the grooves).

Concrete properties

- The mortar (at least, near the surface) should be consistently strong, durable, and wear resistant. Mix design is a key factor, but so are proper placement techniques, including finishing and especially curing.
- Siliceous sands should be used whenever possible in order to improve durability and friction.
- For diamond ground pavements, the makeup of the concrete is exposed at the surface. Because the majority of the concrete used in paving consists of coarse aggregate (rock), the nature of this constituent will significantly affect the ability of the surface to retain the texture necessary for both a quiet and safe surface. As with any pavement related decision, careful consideration should be given to friction. With respect to diamond grinding, selection of projects and grinding patterns should be based on experience and/or a careful evaluation of the concrete material, and more specifically, the coarse aggregate type.
- For tined textures, there should be an adequate and consistent depth of mortar near the surface to hold the intended geometry.

Joints

- If joints are present, they can contribute to not only overall noise level, but also annoyance.
- Narrow, single-cut joints are preferred over widened (reservoir) cuts.
- Faulted joints should be avoided by providing adequate load transfer.
- Excess joint sealant should be avoided, especially if it protrudes above pavement surface.
- Spalled joints should be prevented through proper design, materials selection, and construction.

Summary of Better Practices to Reduce Tire-Pavement Noise

Concrete Materials Selection and Proportioning

- **Aggregate gradation**—for tining and drag surfaces, having adequate mortar concentration near the surface is a critical variable. Ideally, this could be achieved with a consistent, dense mixture. While it is important to have a nominally ideal mixture, consistency of the mixture as batched and placed is paramount.
- **Aggregate selection**—selection of fine aggregate should be made with friction in mind, and thus siliceous sands are preferred over calcareous sands. Coarse aggregate type is of consequence if the aggregates are expected to become exposed, either through surface wear or diamond grinding. The selection of a hard and durable aggregate is therefore preferred.
- **Mortar quality**—a high-strength, low permeability, wear resistant mortar fraction will help maintain the intended texture over time. Measures to lower the w/cm through the use of SCM and/or chemical admixtures should be used when possible. Although they may promote bond for concrete overlays, sticky mortars should be avoided, as they may not hold the texture as intended, and instead deform under action of tining. Mortars that are too fluid could lead to grooves that slump or close-up. Both extremes in mix consistency may lead to unintended or undesirable texture.

Paving Equipment

- **Minimize vibrations**—to minimize texture in the pavement surface that repeats itself on the order of 1 in. (25 mm) or longer, vibrations in the paver should be avoided—at least, vibrations that could potentially be imparted into the slab surface at the profile pan.
- **Uniform paver motion**—ideally, the paver should move as smooth and consistent as possible. In addition to "obvious" problems with sudden starts and stops, even the impact of poorly maintained paving tracks can potentially impart undesirable texture features, as can small but rapid adjustments of the paver resulting from improper elevation and lateral control systems (e.g., stringline).
- **Uniform extraction**—heavy paving equipment would be preferred as a means to control variations in the pavement surface. Maintaining a constant head of uniform concrete at the proper level is also important.
- **Equipment maintenance**—equipment maintenance activities should not be overlooked. Jerk or vibration from poorly-maintained equipment can manifest itself as texture variations in the pavement surface.

Texture/Cure Equipment

- **Minimize vibrations**—especially important for tined surfaces where vibrations of the tining rake can potentially impart undesirable texture.
- **Cleanliness**—for drag and tined surfaces, the texturing medium will always be contaminated to some degree with latent mortar. Care should be taken that the buildup of latency is not so significant as to depart from the intended texture.
- **Consistent tracking**—texture equipment should have a stable and consistent footing and minimize lateral wander. Track-driven equipment may inadvertently introduce small, repeating texture irregularities, as can wheeled devices due to wheel hop or imperfections. Wheeled devices have a disadvantage in their ability to maintain constant traction.
- **Heavy duty curing**—curing is paramount to the durability of the pavement surface. While often done immediately after texturing on the same cart, this process cannot be compromised in terms of the timing or application rate. Multiple pass (or higher concentration) curing application is recommended whenever possible.
- **Equipment maintenance**—like with the paver, proper and routine maintenance could improve the working condition of the texture/cure equipment, potentially preventing unwanted jerk or vibrations.

Grinding Equipment

- **Grinding head**—there does not appear to be an optimum size and spacing of blades and spacers to reduce tire-pavement noise as there is for improving friction (as a function of aggregate type). Conventional practice selects these components based on the specific concrete being ground in order to optimize production rate and the durability of the surface from subsequent wear under traffic and maintenance. This practice is still recommended to better ensure that safety, cost, and durability are not compromised for the sake of noise.
- **Size**—larger, heavier grinding equipment is more likely to have the control necessary to consistently impart the texture at the intended depth and lateral coverage.
- **Holidays and overlap**—care should be taken that the match line between passes of the grinder does not coincide with the wheel path, as this can be a source of irregular grinding patterns. Wider grinding heads (e.g., 4 ft. – 1.2 m) will minimize the number of match lines, keep them out of the wheel path, and potentially impart better control.
- **Bogie wheels**—any imperfections in the bogie wheels that support the grinding head can manifest as texture variations in the as-ground surface. Care should be taken to ensure that the wheels are true (round).
- **Fins**—measures should be taken to minimize the variability in the height of the remaining fins of concrete. While some fin wear can be expected under traffic and from winter maintenance activities, excess fin heights should be avoided by configuring the grinding head with the appropriate spacers (primarily a function of coarse aggregate type).
- **Vibrations**—while inevitable due to the nature of grinding, excess vibrations should be avoided. If unchecked, these vibrations can impart themselves as undesirable texture in the pavement that can, in turn, increase noise levels, especially that texture which repeats itself on the order of 1 in. (25 mm) or longer.

Figure 5 further illustrates the transverse tining section by way of a texture scan measured with the three-dimensional texture profiler, RoboTex *(8)*. Subtle curvature of the lands between the tine grooves can be noted in the louder section, while the tine grooves are much less aggressive in the quieter section. Note that the texture depths were very similar; the differences in geometry of the lands was the major contributor to noise—largely due to the land (tine) spacing, which was in excess of 1 in. (25 mm) in many cases. This as-constructed variability in texture is another example of the impetus for better practices.

Ideally, the probability of constructing the nominal texture should increase as better practices are followed.

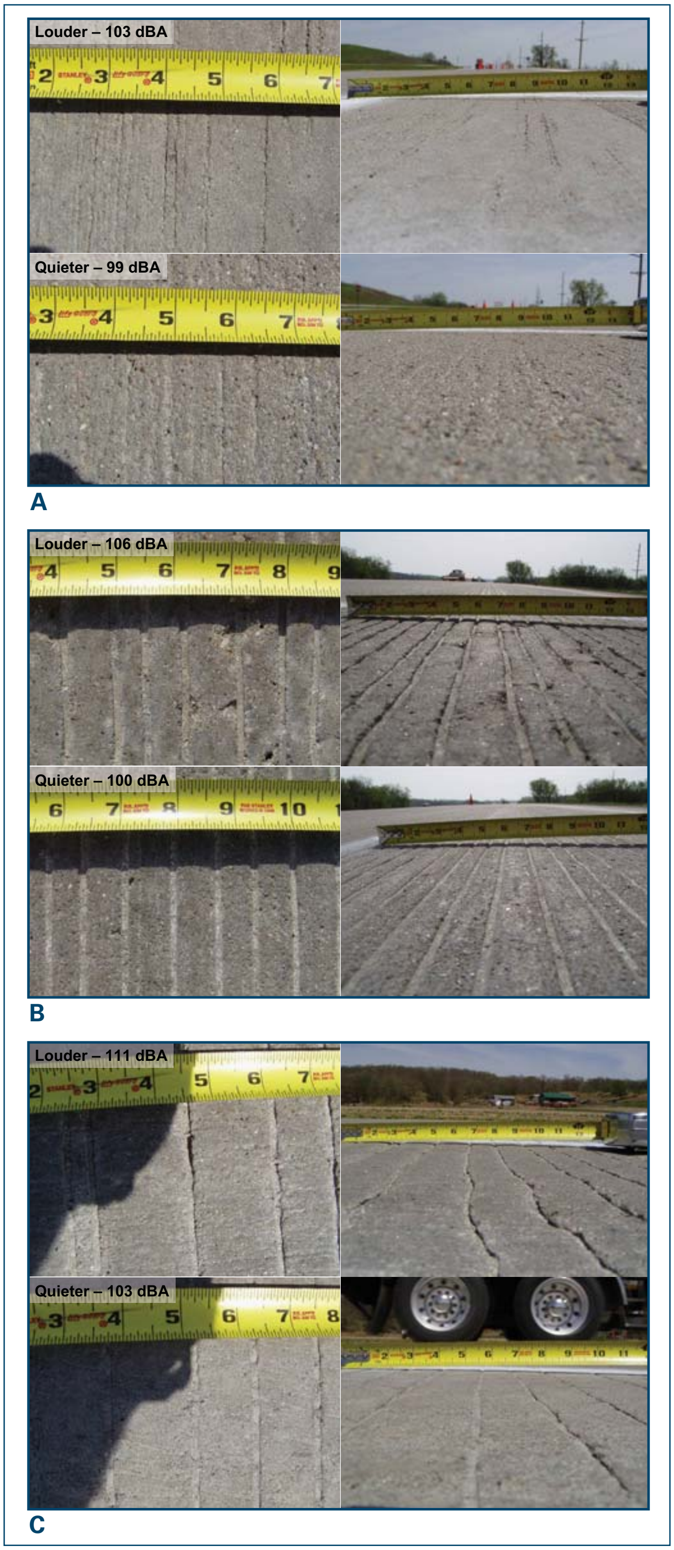

Figure 4. Variability of drag (a), longitudinally tined (b), and transversely tined (c) surfaces and their effect on OBSI noise level

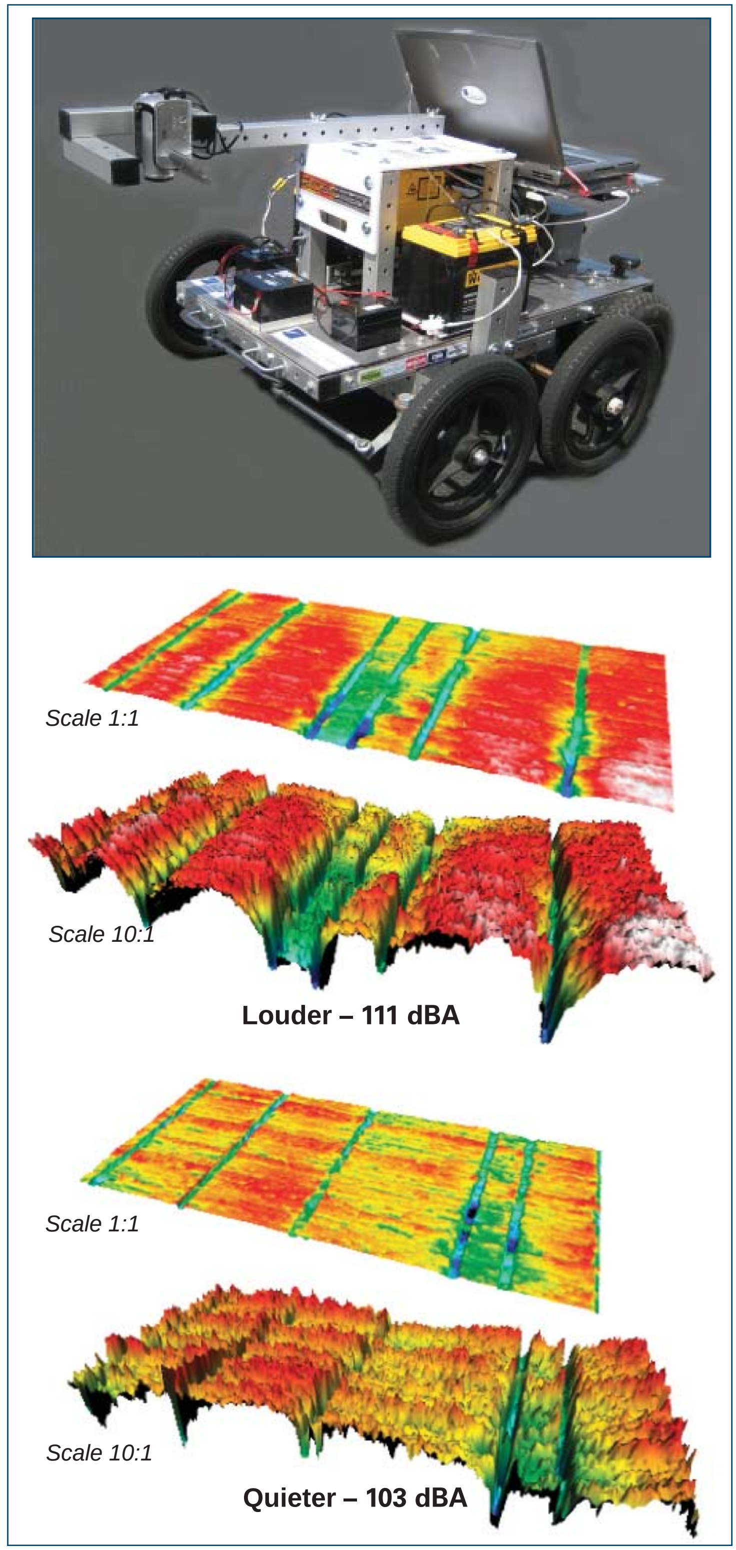

Figure 5. RoboTex device and scans of 100×200 mm samples showing variability of transverse tined surface and its effect on OBSI noise level

Conclusions

For today, the concrete pavement community can promote better practices that focus attention on what should be improved upon in today's concrete spreads. For tomorrow, the solution will likely be automation of the texturing operation.

Over the years, slipform concrete paving operations have become more and more automated. Automatic grade control, for example, is now a standard feature for most slipform pavers. Monitoring vibrator functionality and frequency is also common.

To meet the demands for predictable low-noise surfaces, automation will allow the paver, texture cart, and grinding operators to monitor the texture being produced and to make adjustments on the fly. Ultimately, this approach will be the best way to achieve a specified "target texture" on concrete pavements.

For now, we can make significant improvements by adopting better practices.

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About the Concrete Pavement Surface Characteristics Program

In December 2004, a coalition was formed between the National CP Tech Center, the Federal Highway Administration (FHWA), ACPA, and IGGA. The mission was to help optimize concrete pavement surface characteristics. More specifically, it was to find quieter pavement solutions that won't compromise safety, durability, or cost effectiveness.

The current program is now working 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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About the National Concrete Pavement Technology Center

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.