How to Design and Construct Quieter Concrete Pavements

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Abstract
Concrete pavements can be designed and constructed so that the sound generated upon driving them can be as quiet as any other conventional pavement type in use today. The question is how can this be done, and furthermore, done consistently. This paper provides an overview of guidance developed under the Concrete Pavement Surface Characteristics Program titled, How to Reduce Tire-Pavement Noise: Better Practices for Constructing and Texturing Concrete Pavement Surfaces. Constructing a quieter concrete pavement requires the texture to have certain fundamental characteristics, but just as important is an emphasis on uniformity during construction. Furthermore, while there have been innovative equipment and techniques that have shown promise of quieter pavements in the future, it has been found that quieter concrete pavements are routinely built around the world using the same nominal concrete pavement textures in use today, namely diamond grinding, drag, longitudinal tining, transverse tining, and exposed aggregate.

Introduction

It can be shown that concrete pavements can be designed and constructed so that the sound generated upon driving them can be as quiet as any other conventional pavement type in use today. The question is how can this be done, and furthermore, done consistently.

To begin, it is important to understand the fundamentals. It has been found that quieter concrete pavements are routinely built around the world using virtually all of the same nominal concrete pavement textures in use today, namely diamond grinding, drag, longitudinal tining, and even transverse tining (Rasmussen 2008).

Some might argue then that quieter concrete pavements must somehow sacrifice safety. However, the data has proven this false; there is no relationship between friction and noise. As illustrated in Figure 1, quieter surfaces vary in friction in the same way that louder surfaces do. In this figure, tire-pavement noise is shown as measured with on-board sound intensity (OBSI) (AASHTO 2011) and is compared to friction values that are transformed into a metric that is commonly used by state highway agencies in the USA (ASTM 2006).

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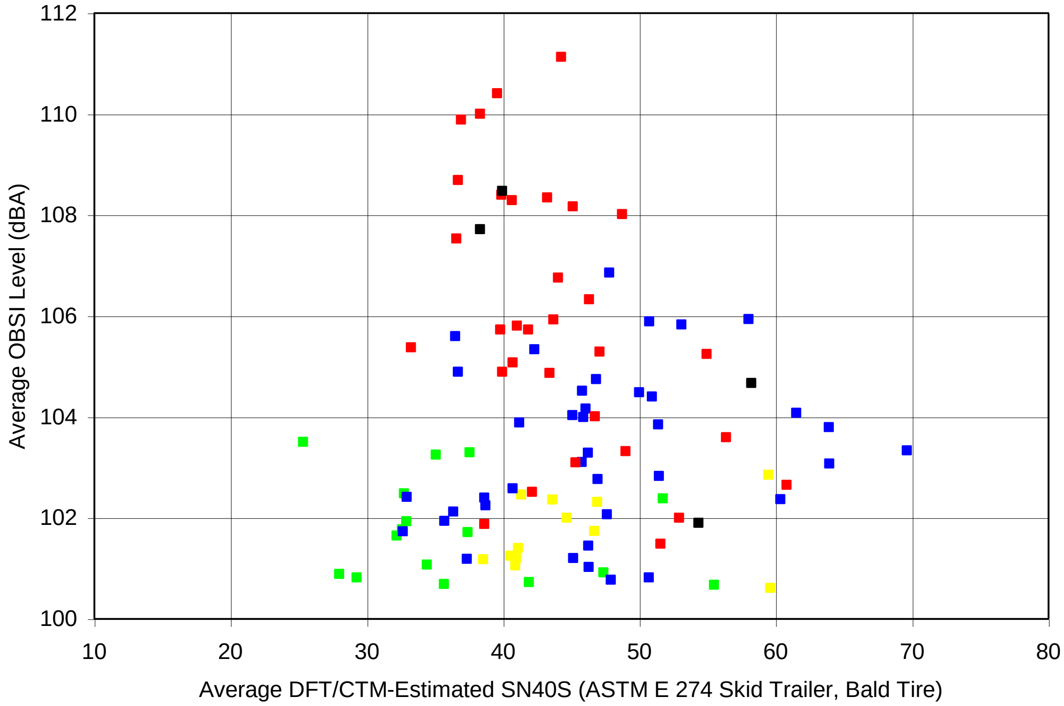

Figure 1. Tire-pavement noise levels versus pavement friction levels for various concrete pavements.

Quieter concrete pavements can be built to be not only quiet and safe, but also durable and cost effective. Given all of this then, why is it that not all concrete pavements are quiet? One problem that has been faced until recently is the lack of a collective understanding of what makes some concrete pavements quiet and others not. To address this in recent years, the National Concrete Pavement Technology Center (CP Tech Center) at Iowa State University has amassed the largest database so far of concrete pavement surface characteristics, including measurements of noise, texture, and friction. Nearly 1,600 test sections throughout North America and Europe have been evaluated (Wiegand 2009).

From this, the Concrete Pavement Surface Characteristics Program (CPSCP) has developed an understanding of the fundamental surface properties that affect noise. Based on this knowledge, better practices that serve to avoid those surface properties have been developed. As part of the evaluation of the concrete pavement textures measured to date, both the “best” and the “worst” of virtually every nominal concrete pavement texture in use today has been catalogued. With so many measurements, distributions have emerged showing what noise characteristics are possible for each nominal texture type. Like in other ways that a pavement would be judged—smoothness, cracking, faulting—pavements throughout the world vary in their quality. Noise is no different. The distribution that has been found is due to differences in design, construction, age, climate, and traffic, among many other factors.

With respect to tire-pavement noise, Figure 2 illustrates the range of levels that have been measured on the pavements to date. The pavements are broken down by nominal texture type and shown as normalized distributions of the noise levels evaluated using OBSI (AASHTO 2011). It should be noted that the pavements measured under the CPSCP do have a bias towards those earlier in life since one of the program goals is to link the measurements to construction factors that are generally only available for younger sections.

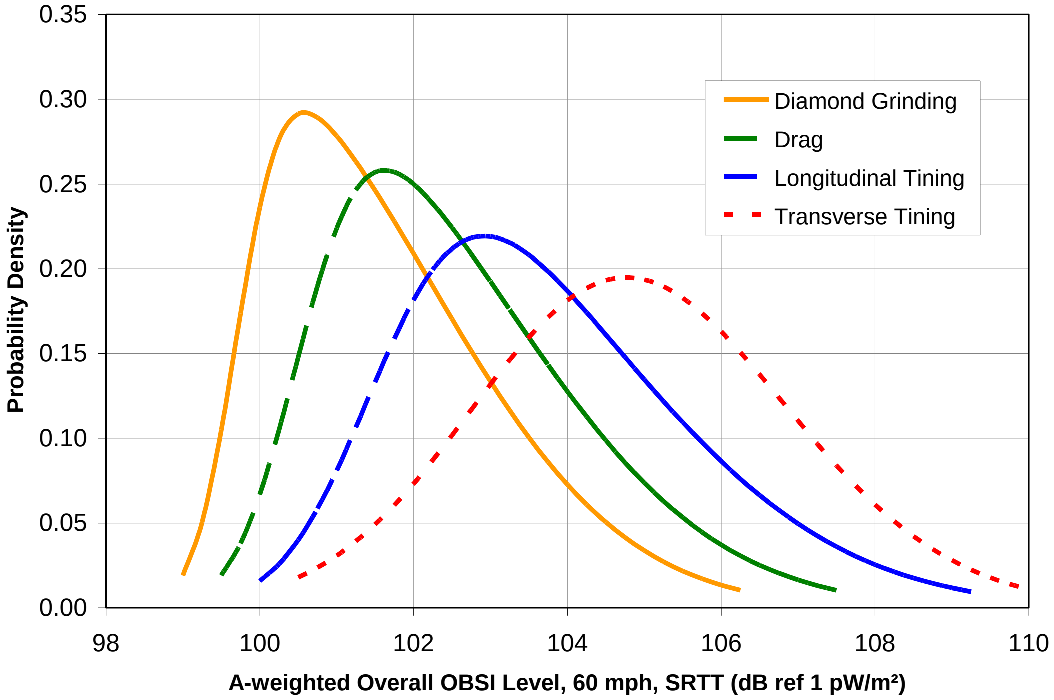

Figure 2. Normalized distributions of OBSI noise levels for conventional concrete pavement textures.

Based on the work conducted to date, an A-weighted tire-pavement noise level of approximately 101 dB (ref 1pW/m²), measured using OBSI at 96.6 km/h (60 mph), appears to be a reasonable target threshold for new concrete pavements (Cackler 2006 and Ferragut 2007). With this in mind, and referring to Figure 2, the following can be concluded:

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

From these data, it can be concluded that virtually all conventional nominal textures have the potential to be constructed as quieter concrete surfaces, although some have a higher probability than others do. While selection of the nominal texture would be the first logical step toward achieving the goal of a quieter pavement, this was not the sole intent of this study. Instead, better practices are necessary to help owner-agencies and/or contractors achieve the quietest surface within any given nominal texture. Developing the better practices, however, requires tapping into the combined experience of both concrete paving contractors and paving equipment manufacturers.

Summary of Better Practices

To build a quieter concrete pavement, one must do the following:

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

The first item has been addressed in large part under the CPSCP and through the results of numerous other studies (Ferragut 2007, FEHRL 2006, Sandberg 2002). Figure 3 summarizes some of the key relationships and can serve as a reference for those seeking to better understand the link from the design and construction to the most relevant as-constructed properties affecting tire-pavement noise.

Concrete Pavement Surface Properties that affect Tire-Pavement Noise

- **Surface texture (bumps and dips)**
  - Avoid (flatten) texture that repeats itself at intervals of 25 mm (1 in.) or larger.
  - Avoid extremely smooth (e.g., floated or polished) surfaces; instead, some fine texture (that is on the scale of 3 to 6 mm – 1/8 to 1/4 inch) 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.
- **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.
  - Given that there may be conflicting objectives between what is required of the concrete near the surface and what is needed both structurally and for economy, two-lift construction may be a consideration.
- **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.

Figure 3. Concrete pavement surface properties that affect tire-pavement noise.

Better practices to improve surface properties and thus tire-pavement noise are really about establishing a higher order of control over the texture and other surface properties. It is not about designing or building innovative surfaces, but rather the control of conventional texturing techniques. There should be a renewed awareness of the impact 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 (eventually) the texturing and curing (the latter being important for acoustical durability).

Figure 4 summarizes the better practices that are described in more detail elsewhere (Rasmussen 2008). Like Figure 3, this figure can serve as a helpful reference for understanding the numerous issues at play that affect tire-pavement noise.

These are, of course, just a few of the better practices that could be adopted if reducing tire-pavement noise is of concern. Many of these are better practices that will also improve smoothness, durability, and, in some cases, 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 5, will ultimately affect the final texture.

Figures 6 through 8 illustrate this further. These photographs show how variability in the as-constructed texture can, in turn, lead to very different tire-pavement noise levels (in this case, shown as OBSI measured at 96.6 km/h (60 mph) with the SRTT) (AASHTO 2011). These photographs were taken on one of the CPSCP test sites on US Highway 30 in Iowa (Ferragut 2007). In each figure, 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 texture characteristics noted in Figure 3 can be observed. Figure 9 further illustrates the transverse tining section by way of a texture scan measured with the 3-dimensional texture profiler, RoboTex, illustrated in Figure 10 (Ferragut 2007). From this, 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. It should be noted that the texture depth in both cases was 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 25 mm (1 in.) 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.

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 dense mixture along with modified methods of finishing. Alternatively, and while not necessarily ideal for smoothness, durability, or cost, mixtures with high mortar fractions appear potentially better in terms of their ability to "hold" the intended texture. While it is important to have a nominally ideal mixture, consistency of the mixture as batched and placed is paramount. Innovative options such as two-lift concrete paving might be a consideration in the future in order to balance these potentially competing mix objectives.
  - *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 25 mm (1 in.) 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 the 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 may be overlooked as a potential source of jerk or vibration that 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., 1.2 m – 4 ft.) 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 wear will occur under traffic and from winter maintenance activities, additional means of knocking down excess fin height can be done. Dragging the surface with a steel blade or beam prior to opening to traffic can reduce fin height, but may also damage pavement joints, and is therefore not recommended.
  - *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 25 mm (1 in.) or longer.

Figure 4. Summary of better practices to reduce tire-pavement noise.

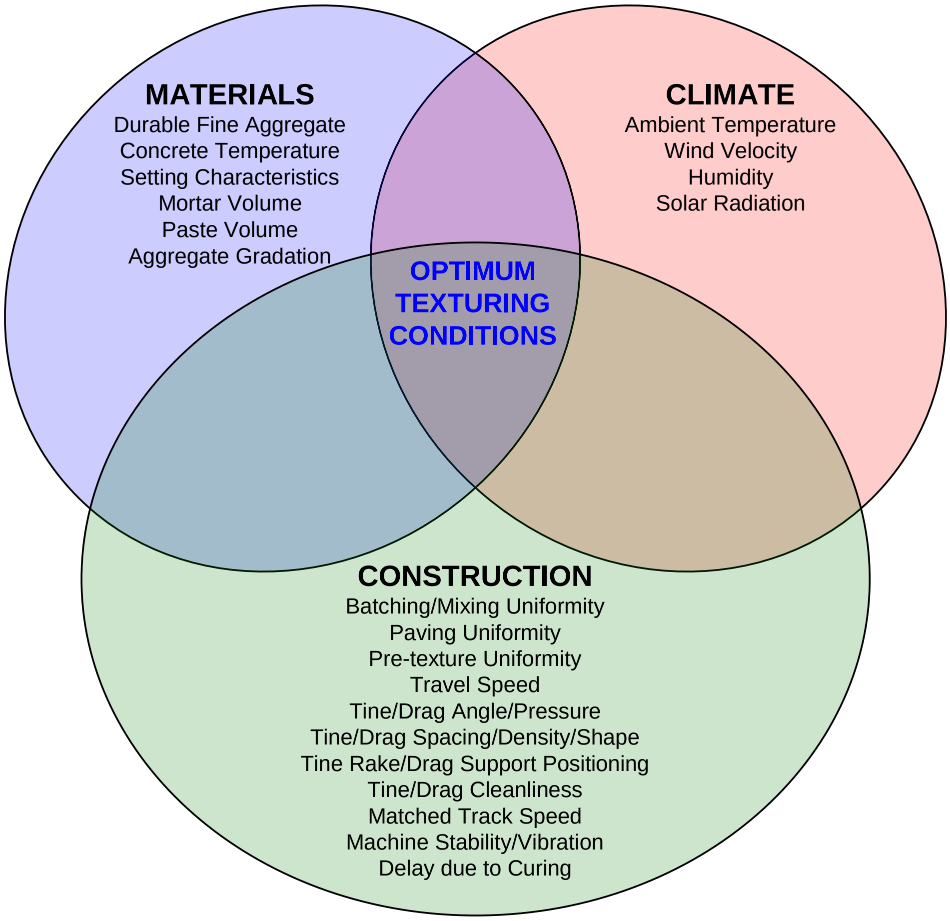

Figure 5. Variables affecting texture and the concept of an optimum texture window.

Figure 6. Variability of drag texture surface and its effect on OBSI noise level.

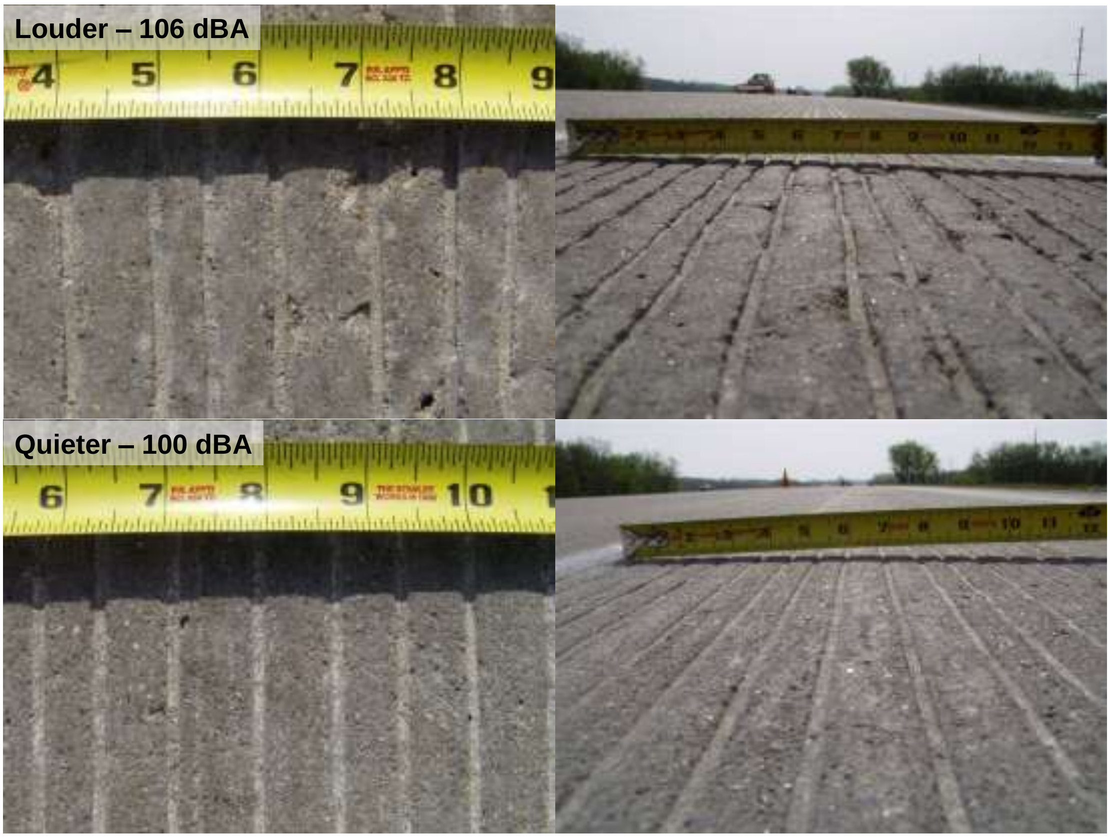

Figure 7. Variability of longitudinal tined surface and its effect on OBSI noise level.

Figure 8. Variability of transverse tined surface and its effect on OBSI noise level.

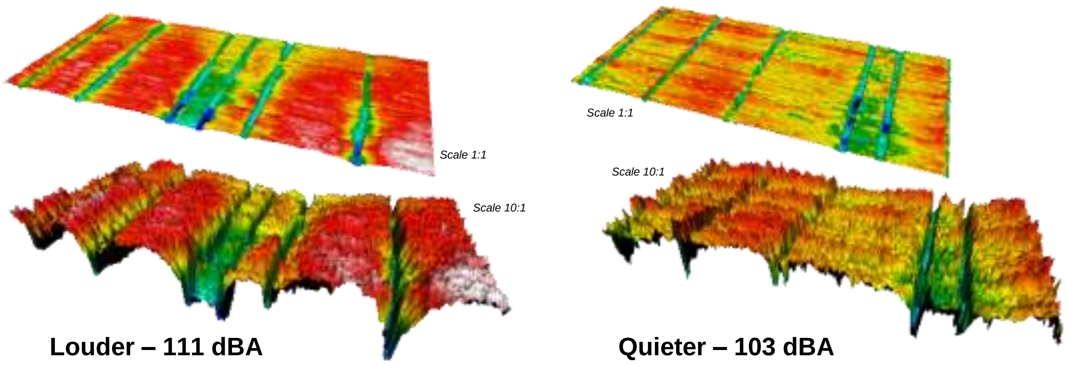

Figure 9. RoboTex scans of 100×200 mm samples showing variability of transverse tined surface and its effect on OBSI noise level.

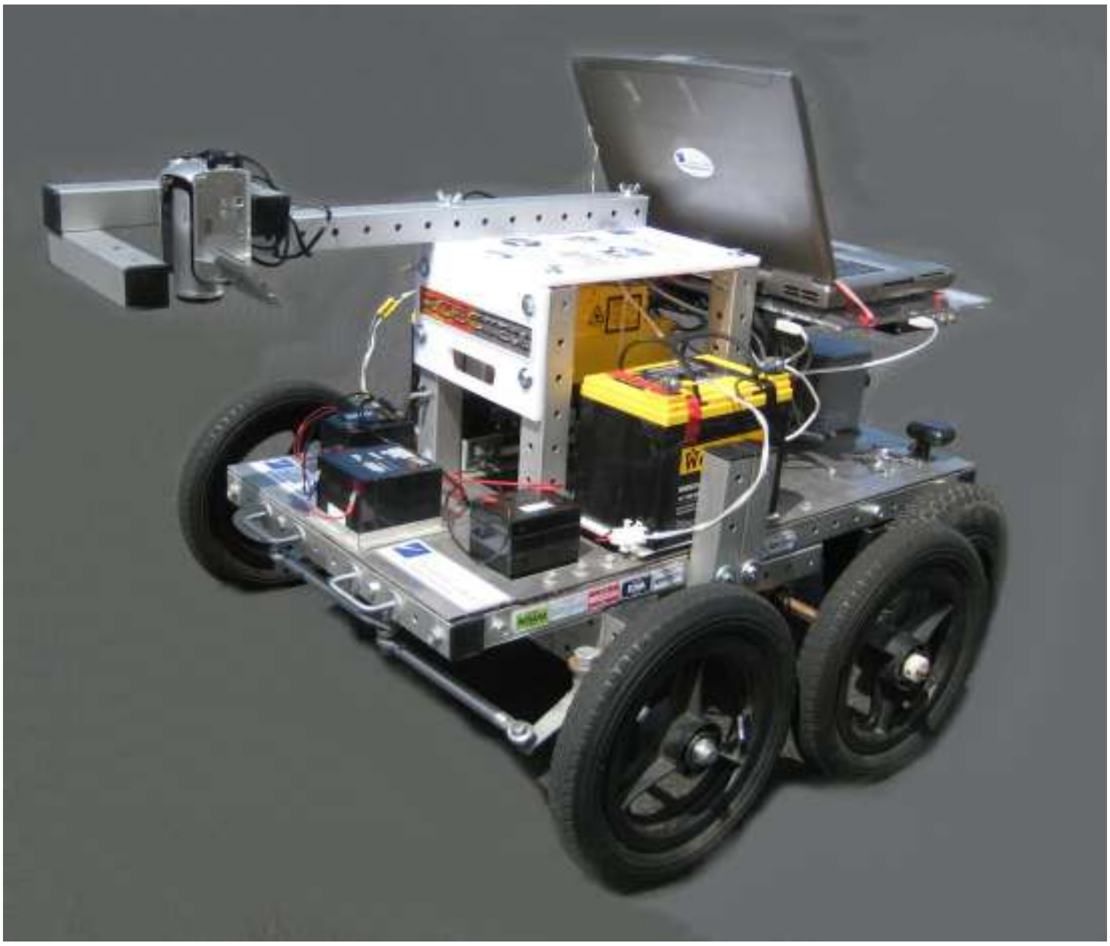

Figure 10. Robotic-based Texture (RoboTex) Measurement System.

Conclusions

For today, the concrete pavement industry can promote better practices that focus attention on what should be improved upon on 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 virtually standard feature for most slipform pavers. Monitoring vibrator functionality and frequency is also common. Maybe the texturing operation is next.

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 may be the best way to achieve a specified "target texture" on concrete pavements. For now, we can make significant improvements by simply adopting these better practices.

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