

The logo for 'inter noise' features the word 'inter' in green, a red cross symbol, and the word 'noise' in green.

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NOISE CONTROL FOR QUALITY OF LIFE

## Designing and constructing pavements to comply with the ISO 10844:2011 exterior noise test track standard

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### ABSTRACT

As the ECE and other regulations worldwide continue to evolve, the ISO 10844:2011 exterior noise test track standard will be an important component of vehicle and tire noise testing in the coming years. Tracks that had previously complied with the 1994 version of the standard are not necessarily conforming to the new standard, which has led to many owners to seek out resurfacing projects. With pavements, the design, materials selection and proportioning, and construction techniques all affect the end result. Pavement engineering is often focused on pavement life, and for test tracks, this is defined by functional performance including changes in friction, rolling resistance, ride, and in this instance, noise. Designing and constructing ISO 10844 surfaces can be challenging. In addition to the balance between initial cost and durability, there are several unique requirements that are uncommon in highway pavements. Acoustical absorption and texture requirements, for example, challenge even the most experienced road builders. However, meeting these new challenges can also lead to new opportunities. Desired texture and absorption can be realized through an understanding of the myriad of design and construction variables. The result is not only more predictable and consistent test outcomes, but increased longevity of these surfaces.

Keywords: Passby Noise, Pavement, ISO 10844

### 1. INTRODUCTION

External vehicle noise testing is an integral component of regulatory compliance. For example, UNECE R41, R51, and R117 [1-3] regulations have a common requirement for a pavement test surface that is in general conformance with ISO 10844. The current ECE regulations incorporate language from the 1994 version of the ISO standard [4]. However, recent proposals to the UNECE Working Party on Noise (GRB) include changes to these regulations that would require test surfaces as described by ISO 10844:2011 [5].

An ISO 10844 surface is intended to be a dense-graded hot-mix asphalt pavement which is representative of a high-quality highway pavement found worldwide. The standard was further developed to facilitate the construction of a pavement so that with all else being equal, the same external noise test result should be measured from track to track [5].

Ultimately, compliance with ISO 10844 can affect everything from type approval and homologation, to tire labeling, to reporting by the automobile press [6,7]. Furthermore, the ECE is just one example of regulatory bodies worldwide that are seeking to update their requirements to

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include ISO 10844:2011. SAE also includes ISO 10844 by reference in J1470 [8], and it is under consideration for future revisions to other standards sponsored by the Light Vehicle Exterior Sound Level Standards Committee (TEVSL10).

When the 2011 version of ISO 10844 was published, it was not the intent to change the pavement test surface. Instead, the updates were to facilitate greater uniformity between tracks. Some of the impetus stemmed from previous reports on track-to-track variability [9-12]. The changes in 2011 were also intended to update the specification with respect to advancements in both pavement technology and measurement methods [5].

In addition to Annex D of ISO 10844:2011, numerous individuals have previously reported on new aspects of the ISO 10844 standard [13-17]. Rasmussen, et al. has also reported on various challenges with respect to engineering pavements to comply with the new ISO 10844 standard [18,19]. The intent of this paper is to expand on some of these challenges as they relate the design, construction, and maintenance of pavement surfaces to the requirements of the ISO 10844:2011 standard.

For proving ground and test track owners with a nonconforming ISO 10844 surface, overcoming these challenges during resurfacing can seem daunting. However, while the principal objective is to construct a compliant surface, there is also opportunity to construct a surface that can provide additional value. For example, a pavement can be constructed that is not only compliant, but also on the “quieter side” of the ISO specification. Given that ISO test tracks commonly evolve so that sound levels increase over time, the latter goal enables an owner to extend the useful life of the test track, and thus lower life-cycle costs.

## 2. PAVEMENT ENGINEERING

Prudent pavement engineering at a test track or proving ground should consider the entire pavement life cycle including planning, design, construction, and management. Specific goals should include:

- Reduction in life-cycle costs by improving asset management practices, making the most of both capital improvement and operations and maintenance (O&M) funds.
- Reduction in construction costs through specialized and efficient designs coupled with construction oversight that balances quality and risk.
- Improvement in quality through an inherent understanding of a pavement’s influence on vehicle and tire responses including friction, rolling resistance, ride, or in this instance, noise.
- Optimization of pavement properties to not only meet specified requirements, but also facilitate consistency in test results over time.

Engineering is often targeted to performance goals. Pavement engineering categorizes performance as follows:

1. Structural performance – the ability of a pavement to resist traffic loading;
2. Material performance – durability of paving materials to environmental effects (principally climate and moisture) and a compatibility between paving materials;
3. Functional performance – durability of the tire-pavement interaction through resistance to changes in responses such as ride, friction, rolling resistance, and noise.

Engineering a pavement to meet multiple performance goals is possible, but it can be challenging. To succeed, a systems approach becomes necessary, with pavement engineering implemented as part of design, construction, and in the management of the pavements over time [20-22]. With a feedback loop established, significant improvements in pavement quality are possible since pavement management data can be used to make intelligent decisions about how to improve forthcoming pavement design and construction.

### 2.1 Pavement Engineering in Design

Each performance goal requires specific elements to be incorporated into the pavement design. For example, a need for structural performance affects pavement layer thicknesses. However, while often a principal consideration for public highways, structural performance is generally of lesser importance for most ISO 10844 surfaces. Of course, owners of proving grounds operated by heavy truck manufacturers might beg to differ, given frequent pass-by testing of heavy vehicles!

The engineering of an ISO 10844 track begins with pavement design, which includes:

1. Site characterization – quantifying the factors that influence pavement performance, including details about the test traffic, soils, and climate.
2. Pavement surface design – establishing targets for surface texture and absorption, and then

- identifying pavement materials with the greatest potential of achieving those targets;
3. Pavement structural and material design – selecting pavement materials and thicknesses to assure durability during the course of the pavement life. Resistance to both traffic and the climate are considered, with the latter being a particular challenge in test facilities subject to large temperature changes throughout the year (e.g., desert or cold-weather regions).
  4. Life-cycle analysis for management, maintenance, and rehabilitation – development and comparison of design alternatives encompassing various lives to find a rational balance between initial cost and longevity.
  5. Materials and construction standards and specifications –unlike other surfaces at proving grounds, “typical” asphalt mixtures are not acceptable for ISO 10844 tracks. The language selected to specify the materials and construction are of paramount importance if design targets are to be achieved.

## 2.2 Pavement Engineering in Construction

Pavement engineering during construction is also important. At the very least, a constructability review should be conducted in order to assess the techniques proposed by the contractor. The following are examples of common issues warranting consideration:

1. Sequencing of paving, including project access, to avoid trafficking the newly laid asphalt surface with construction equipment.
2. Means to construct the joints between adjacent asphalt strips. One objective of better jointing is to minimize “steps” across the joint that can lead to a nonconforming surface per ISO 10844:2011 (see Figure 1a). Furthermore, poor technique can also lead to low asphalt density at the joints, which in turn can lead to poor performance. Water and air will more readily penetrate areas of low density, deteriorating the asphalt material at these locations (see Figures 1b and 1c).



Figure 1 – Poor joint construction (a,b) and deteriorated asphalt material (c)

3. Means to minimize segregation of the asphalt material. Segregation can lead to a non-uniform texture (see Figure 2). The ISO 10844:2011 standard includes new provisions for “homogeneity” that are of particular relevance. Numerous factors affect segregation, and thus a constructability review must include the means of production, transport, and paving.

Construction activities that warrant additional engineering include the review of field design changes and value engineering (V-E) proposals. The latter can be of particular benefit to an owner, since with a V-E, the contractor is encouraged to propose innovative practices that save money and result in an “equal or better” product.

Construction oversight of ISO 10844 tracks also benefits from pavement engineering due to the highly specialized nature of these surfaces. What would sometimes be considered “acceptable” practice in asphalt paving might inadvertently affect these unique paving surfaces. For example,

raking loose asphalt material from the joints across the mat (before compacting) is a common practice in asphalt paving (see Figure 3a). However, on ISO 10844 surfaces, this practice can have potentially detrimental consequences to both texture and acoustical absorption.



Figure 2 – Segregated asphalt can lead to coarse texture (a) within a meter of fine texture (b)

**2.3 Pavement Management**

To confirm conformance of a new or existing ISO 10844 surface, a series of specialized tests are required. These tests include measurements of geometry, surface irregularities, texture, and acoustical absorption. The latter three tests are required every 2 to 4 years in order to comply with the new “periodical checking” requirement of ISO 10844:2011.

The data collected during these tests can be used in conjunction with other data more routinely collected by the owner. For example, “sand” patch testing for texture depth (which now uses glass beads in lieu of sand) was required in ISO 10844:1994 (see Figure 3b). This has since been replaced by the mean profile depth (MPD) in the 2011 standard, but due to its simplicity and correlation to MPD, sand patch data can still be used to assess evolution of the surface [23].

Using pavement management methods, sand patch and other test data can be used along with pavement engineering models to monitor the performance of the ISO test track. With these capabilities, it is possible to predict the date that reconstruction of the ISO 10844 surface may be necessary. Furthermore, through modern visualization tools within pavement management systems, the source of the deterioration can be more readily determined [22] (see Figure 3c). It is particularly helpful when construction quality data is layered into the same management system.



Figure 3 – Constructing undesired texture (a), measuring with sand patch (b), managing pavement texture (c)

**3. PAVEMENT SPECIFICATIONS**

In introducing the topic of pavement engineering, it is worthwhile to discuss pavement specifications in a broader sense. The quality control and specification of pavement construction has evolved over the last 100 years. Changes in specifications have resulted from “lessons learned” from previous projects, as well as advancements in both paving and measurement technologies.

**3.1 Specification Types**

There are effectively three different approaches in specifying pavement construction:

1. Means and methods (prescriptive) specifications;
2. End-result specifications; and
3. Warranty specifications.

The first approach has traditionally been used by most owners. The paving contractor is instructed on what materials and equipment to use, and how to use them. The ISO 10844:2011 standard includes provisions that would be considered prescriptive, including the so-called “sieving curve” or gradation requirement, for which a “recipe” is prescribed for each size of aggregate (gravel, sand, fines) used in the asphalt mixture.

End-result specifications are a second unique approach that give the paving contractor relative freedom to select the materials and equipment to use. Instead, the final pavement is measured for properties that are of particular importance to the owner. For example, ISO 10844:2011 has two very important end-result requirements that are new to most pavement contractors: texture and acoustical absorption.

The third specification approach is warranties. While routinely used in other industries, warranties are only recently increasing in popularity for pavement construction. Under a warranty specification, the pavement can be constructed with relative freedom in means and methods and little to no reporting of the end-result. The unique aspect of these specifications is that the performance of the pavement over time (typically 5-15 years) remains the responsibility of the contractor. The owner of an ISO 10844 track would require the specified requirements (e.g., texture) be maintained for a warranty period. If the texture falls out of compliance, then the contractor would be required to correct (rebuild) at their expense.

Of course, each of these three specification approaches has both benefits and costs, and risk is an important factor. With increasing risk to the contractor (from means & methods moving towards warranty), there will be an increase in the price of construction. The optimum specification for a given project will often be driven by the magnitude of the project. While an ISO 10844 test track alone would not lend itself to a warranty approach, if bundled with a larger capital investment (e.g., vehicle dynamics area (VDA) or durability loop), a warranty specification could be a viable option to consider.

### **3.2 Combining Specifications**

When constructing ISO 10844 tracks, a local highway agency specification is often used in addition to the ISO standard. The ISO standard does not address many aspects of asphalt paving, and thus this step is helpful to achieve a quality product. However, while combining specifications is beneficial, it can lead to unexpected consequences, particularly for ISO 10844 tracks.

For example, highway agency specifications commonly require a minimum asphalt density after compaction. Density correlates to long-term performance, and is thus an important consideration. However, the equipment commonly used to achieve high density can lead to suboptimal pavement texture that can compromise conformance with the ISO 10844 standard.

Working to harmonize the ISO specification with local agency specifications can be challenging. The owner will require a surface that is compliant with the ISO standard. However, they will similarly desire a pavement that does not compromise on performance (longevity). To achieve this harmonization, each provision in the local agency standard should be carefully scrutinized. Furthermore, end-result specifications should be used whenever possible. Prescriptive specifications should be used sparingly, since they are often the source of conflict with provisions of the ISO 10844 standard.

## **4. PAVEMENT OPTIMIZATION**

Engineering a pavement to comply with the ISO 10844:2011 standard involves an attention to detail that surpasses that required for conventional asphalt paving. The requirements for surface texture and acoustical absorption are particularly difficult, because most owners, engineers, and contractors are unfamiliar with both the theoretical and practical aspects of these tests. Even with a basic understanding, it is common for “trial and error” to be used as a means to achieve a compliant surface.

Given the expense associated with track construction, it is cost effective to engineer a pavement so that conformance can be achieved with the fewest number of iterations. As previously discussed, this is achieved through design, specification, and construction oversight. However, while the primary goal is to construct a product that conforms to the ISO 10844:2011 standard, it is also possible to

optimize the pavement to achieve a more favorable result.

The ISO 10844:2011 standard was developed with the goal of reducing track-to-track variability, however it is still common to measure pass-by sound level differences of 2 to 3 dB(A) between two conforming tracks [19]. Pavement optimization commonly translates into constructing a track that is both compliant and among the quietest of what is possible under the standard. This can be important because over time and under traffic, all pavement surfaces will evolve. With respect to ISO surfaces, this most often manifests itself as an increase in texture, which in turn leads to an increase in sound level over time (see Figure 4).

To achieve optimal texture and acoustical absorption, there must be a particular focus on several aspects of pavement design and construction.

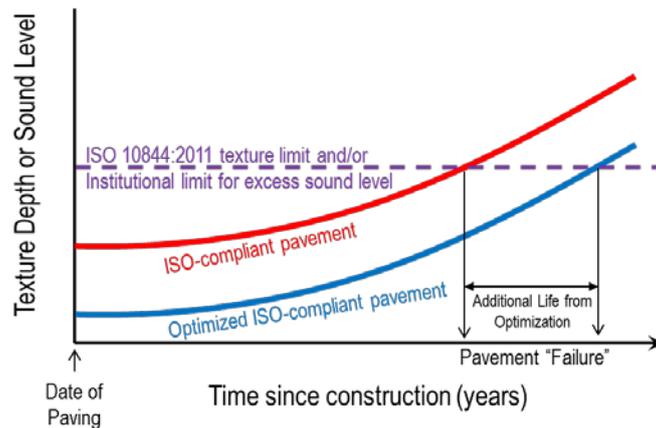


Figure 4 – Engineering quieter and longer-lasting pavements through engineering optimization

#### 4.1 Asphalt Materials

Engineering asphalt pavement materials is not only possible, but also necessary in order to comply with the ISO 10844:2011 standard. In addition to optimizing for texture and acoustical absorption, the engineer must be mindful of the influence that the asphalt mixture can have on evenness, density, cost, and performance. Furthermore, uniformity is a crosscutting requirement since a homogeneous asphalt mixture will generally lead to more consistent test results and a longer lasting pavement, all else being equal.

Gradation of the aggregates in the asphalt mixture is a measure of the size and proportion of the rocks, sand, and fines that are present. In the 1994 version of ISO 10844, specific controls were recommended for the aggregate gradation. However, in 2011, these gradation controls became mandatory. Figure 5 shows the required control bands for the aggregates, with the size of the aggregate particles along the abscissa, and the ordinate representing the percent of aggregates passing (equal to or smaller in size). The figure shown here differs from that published in the ISO 10844:2011 standard; the abscissa is on a “0.45-power” scale instead of a logarithmic scale, and sizes of sieves (screens of varied wire mesh spacing) are shown in lieu of aggregate sizes. Both of these modifications are important to facilitate the understanding of this requirement by the U.S. paving industry.

While these control bands seem straightforward, there can be differences in interpretation since aggregates are graded based on discrete sizes, and thus appear as individual points in this plot. By merely adding or subtracting sieves, a mixture can be shown to pass or fail based on the remaining control points (see Figure 5). Prudent engineering requires that the specification include all commonly used sieves, which is typically more sieves than what are required for conventional highway paving.

All else being equal, quieter mixtures are those that are finer, with a higher proportion of smaller aggregates. Based on this, it would seem reasonable to select a mixture that is the finest possible under the ISO standard (represented as the upper-most curve in Figure 4). However, there is risk in specifying such a mixture since natural variability in the paving material may lead in a non-conforming test result. It is therefore more reasonable to target a gradation that considers the anticipated variability, along with a risk factor. The engineer should also be mindful of systematic changes in the aggregate gradation that result from abrasion during the production, remixing, and

compaction of the mixture. Larger aggregates can break up into smaller pieces, which will affect the results of the gradation of samples collected in the field. Some aggregate types (e.g., sandstone) are more resistant to abrasion than others (e.g., limestone).

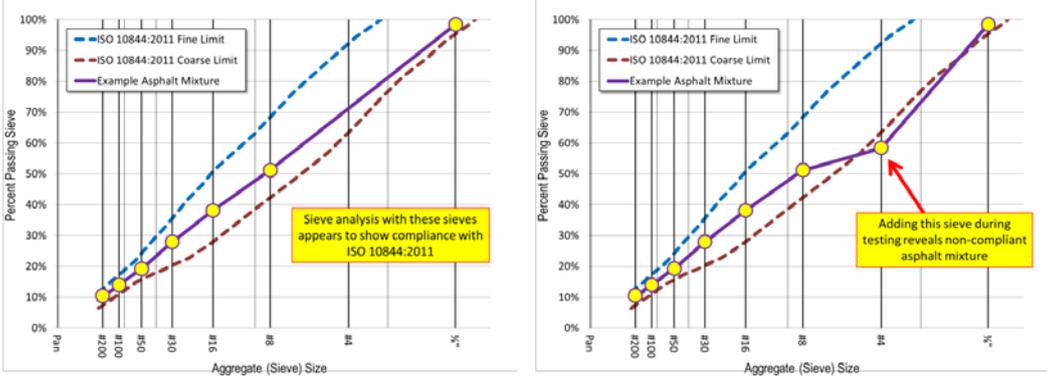


Figure 5 – ISO-specified sieving curve limits, but with discrete sieve testing can show pass (a) or fail (b)

In addition to aggregate gradation, asphalt mixtures contain binder that should be carefully selected. Asphalt binders in the US are most commonly specified using Performance Grading (PG) per AASHTO M 320 [24]. Binders that are PG graded include both a high and low temperature designation that is linked to tests shown to correlate to both low-temperature cracking and rutting (common pavement distresses). Prior to development of the PG system, most asphalt binders were “neat”, meaning that they were a simple product of the petroleum refining process. Under the PG system, polymer modification of asphalt binders is now commonplace. In ISO 10844:2011, polymer-modified binders are permitted, with some limitations. Polymer modification has at least two relevant benefits. The most significant is the potential for engineering a more durable, long-lasting pavement. Secondly, polymer modification can lead to changes in the mechanical properties of the asphalt mixture (namely, the dynamic modulus). All else being equal, these differences in dynamic modulus can have an effect on the tire-pavement interaction.

As a word of caution, binder selection should be made in consideration of the anticipated conditions during paving. While polymer modification can be beneficial, it can also result in a mixture that requires additional compactive effort. During adverse paving conditions (i.e., cold, overcast, windy weather), this can lead to suboptimal density, texture, and absorption if appropriate measures are not taken during construction.

**4.2 Paving Equipment**

Most paving equipment in use today is inherently optimized for maximum productivity and for compliance with two specifications of principal concern in highway paving: smoothness (evenness) and density. For ISO 10844 surfaces, production rates are not a consideration due to the relatively small size of these tracks. Smoothness and density are still relevant; however, texture and acoustical absorption are also important. Equipment selection for asphalt paving under ISO 10844 should include a paver and rollers that are known to produce high quality, uniform paving.

All types of pavers have been used for ISO 10844 construction, but the selection of equipment should be mindful of systematic issues associated with the equipment and/or its operation. For example, some pavers have a propensity to “streak”, leaving trails of asphalt material that are of varied density and texture (see Figure 6a). This can be particularly problematic when wider paving is specified, and the paver extensions are not suitable to produce a consistent product. Alternatively, this characteristic can appear when the paving equipment has not been given ample time to heat up during the laydown process. To overcome this, the screed at the back of the paver has heaters built in; however, each heater may be at a different temperature, which could also lead to streaking.

It is considered better practice in ISO 10844 paving to include provisions for remixing the asphalt mixture prior to running it through the paver. One of the most important considerations in asphalt paving is thermal segregation. Asphalt mixtures will cool at varied rates depending on how they are produced and transported. While not a cure-all, remixing does improve the uniformity of the mixture, which will result in a homogeneous pavement surface.

There are numerous options for rollers used in compacting the asphalt mixture behind the paver. The two most common are steel drum and pneumatic (rubber tire) (see Figures 6b and 6c).

Furthermore, steel drum rollers can be operated in both vibratory and static modes. Steel drum rollers tend to compact through vertical deformation, while pneumatic rollers (with their high inflation pressures) tend to “knead” the asphalt. As a result, both types of rollers will affect the surface texture, but in different ways. There will also be differences in the density near the surface (which strongly correlates to the acoustical absorption).



Figure 6 – Streaking from poor paving practice (a) and pneumatic (b) and steel drum (c) compaction

Timing of compaction is also critical. As the asphalt cools, its compactability changes as a function of the changes in binder viscosity. As a result, the interaction of a roller upon first operation (“breakdown rolling”) is very different from “finish rolling”. Most of the density is achieved in the first one or two roller passes. The asphalt is still warm, and air void reductions and particle re-alignment are more readily achieved. Most of what is accomplished in finish rolling is to eliminate roller marks, leaving a more uniform appearance. The final passes of the roller can affect texture and absorption, but to a much lesser extent.

### 4.3 Innovative Technologies

While refinements to conventional paving materials and process are key to optimizing a pavement, the engineer should also explore the various innovative technologies that are available. Some of the more notable technologies include:

1. **Thermal imaging for quality control** – with thermal segregation of particular concern, this technology can be used to identify potential issues early so that changes in the paving process can be made. Commercially available systems are readily available, such as the Pave-IR system (see Figure 7a), which is cited in paving specifications used by the Texas Department of Transportation [25]. When added to the paver, these systems allow for real-time feedback of the temperature profile across the width of the paving mat.
2. **Intelligent compaction** – this technology is gaining notoriety among the paving industry in the US [26]. There are at least two aspects of this technology that are beneficial. For one, it provides real-time feedback to the roller operator regarding the exact number of roller passes that any area of pavement has experienced. Even though ISO 10844 tracks are small compared to mainline highway paving, it is possible to have some areas of pavement that have been under-compacted, while others have been over-rolled. A second aspect of the technology is the ability for the vibratory rollers to automatically change their operational characteristics (vibration frequency and/or amplitude) based on sensor feedback located on the roller drum. In this way, the pavement will only be compacted to the degree necessary to achieve the intended stiffness. The result is again, a more uniform surface.
3. **Warm mix technology** – in recent years, various techniques have emerged in US paving practice that ensures a more consistent product using “warm-mix” technology [27]. Some technology “foams” the asphalt binder so that more uniform coverage of the aggregates is possible. Other technology includes specialized additives that modify the properties of the asphalt mixture during temperatures that are critical to compaction. In recent years, wax-based warm-mix additives such as Sasobit have been successfully used in ISO 10844 mixtures (see Figure 7b).
4. **Three-dimensional texture profiling** – texture is one of the more unconventional end-result specifications, and yet it is vital to link it to materials and construction.

Measurement technologies such as the RoboTex profiler allow for three-dimensional texture profiles to be measured along both the length and width of the ISO 10844 paving surface [14-16] (see Figures 7c and 7d). With these data, texture depth (MPD) can be calculated and reported with a resolution capable of linking it to changes in rolling pattern, weather (wind speed, in particular), and a multitude of other factors that can impart “construction artifacts”. Conventional texture profilers are not capable of producing the same density of texture data, and are thus of limited benefit in this regard.



Figure 7 – Innovative technologies to improve pavement quality

## 5. SUMMARY AND CONCLUSIONS

Most of the better practices described herein are not unique to ISO 10844 test track construction, but are applicable to any high-quality asphalt pavement. Of course, there are some notable differences, including those practices that affect the texture and acoustical absorption, which are not requirements typical for highway paving.

The intent of this overview is to raise awareness about how seemingly small factors during design and construction can manifest into pavement quality control issues, and ultimately lead to noncompliant surfaces. Pavement engineering can be used to overcome many of the challenges that may arise. The adage of an “ounce of prevention” applies here, since proper control of these factors (and a little bit of luck) will result in an ISO 10844 test surface that is not only compliant, but also provides the owner with a long-lasting pavement.

Beyond engineering for compliance is pavement optimization. In this paper, various methods have been identified that can achieve the latter. To facilitate this higher goal, pavement engineering can also adopt innovative technologies that have benefitted the highway industry in recent years.

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