QUIET PAVEMENT

PT-5

2-3 POINTS

GOAL

Improve human health by reducing tire-pavement noise.

CREDIT REQUIREMENTS

Design at least 75% of the total new or reconstructed pavement surface area for regularly trafficked lanes of pavement where the speed limit meets or exceeds 30 miles per hour (mph) with a surface course that produces tire-pavement noise levels at or below those listed in Table PT-5.1, which describes test vehicle speed parameters and the points corrsponding to the level of noise reduction achieved. Test the pavements according to the on board sound intensity (OBSI) method desribed by the current version of AASHTO TP 76. Compute the total surface area of all trafficked lanes that meets or exceed speed limits of 30 mph and show that a minimum of 75% of this area meets the tabulated criteria for tire-pavement noise. Do not include shoulders, medians, sidewalks and other paved areas outside of the travelled way in the computation.

Table PT-5.1: Testing Speeds and Maximum Average OBSI Noise Levels

		Maximum Average Noise Level	
Facility Posted Speed Limit	**Test Speed**	***2 points***	***3 points***
55 mph or more	60 mph	99 dBA	95 dBA
30 to 54 mph	35 mph	91 dBA	88 dBA
less than 30 mph	Does not qualify for credit		

Details

- One OBSI measurement should be done for each roadway section. A roadway *section* is defined as having the following attributes:
    - The same speed limit over its entire length
    - A straight section at least 500 ft long (the test requires 440 ft)
    - The same nominal surfacing material over the entire length

  Therefore, in some instances a project will need to conduct several OBSI measurements depending upon the number of sections identified. Portions of roadway that do not meet the section definition (usually this means portions that do not contain at least a 500 ft straight section) shall be deemed to have met the criteria for 2 points providing the project has at least one section that has been tested and meets the criteria for 2 points.

- OBSI testing need only be done on one lane of a given roadway in one direction. For instance, on a four-lane divided highway testing need only be done on one lane for one direction only.
- OBSI testing may be completed at any time on the final pavement surface.
- The noise level to compare with Table PT-5.1 values is the weighted average of all tested sections (weighted by the length of each section). For a section that does not have a straight portion of at least 500 ft, but does meet the other two section definition requirements, the OBSI measurement value shall be assumed equal to the 2-point value in Table PT-5.1.

RELATED CREDITS

- ✓ PR-5 Noise Mitigation Plan
- ✓ PT-2 Permeable Pavement

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Experience

BENEFITS

- ✓ Improves Human Health & Safety
- ✓ Increases Aesthetics

DOCUMENTATION

- A list of pavement sections to be built (or reconstructed) and their associated surface material type, AASHTO TP 76 test results, and surface areas, and if design was intended to be quiet or not in accordance with the requirements of this criterion. This may be included as part of the standard project documentation or as a separate document.
- A calculation to indicate the total percentage of trafficked lane pavement surface areas surfaced with quiet pavement.
- A drawing or project map showing locations of quiet pavements. These pavements should be highlighted on the plan, a scale should be on the plan, and the total surface area of each pavement section should be called out as a note on the plan.

APPROACHES & STRATEGIES

- Refer to Sandberg and Ejsmont (2002), which is an excellent overview of quiet pavement options, fundamentals and research, including a comprehensive list of 33 different pavement design guidelines for reducing tire-pavement noise. Where noise reduction levels are mentioned they refer to a newly constructed quiet pavement surface and relate it to a more standard surface; often the surface that was previously used or previously measured. These noise reduction levels are difficult to compare fairly from one test/experiment to another because the reference noise level is different in many cases.
- For concrete pavements, refer to Rasmussen et al. (2008) for typical measurement values and methods to reduce tire-pavement noise.
- Use open-graded hot mix asphalt (HMA) and portland cement concrete (PCC). In general, open-graded pavements have shown noise reductions from 3-8 dBA although numbers vary greatly depending upon materials, design and measurement techniques (Sandberg & Ejsmont, 2002). The following mixture qualities generally lead to less tire-pavement noise:

  - **High porosity**. This means a high level of interconnected air voids on and near the surface. Typically effective air void content ranges are 15-30% with air void contents above 20% being better.
  - **Smaller maximum aggregate sizes**. Sizes under 0.4 inches tend to work well with even smaller sizes working even better.
  - **Smooth surfaces**. Especially important in the range of "Megatexture" and "Macrotexture." Megatexture refers to pavement surface elevation changes on the order of 2-20 inches in wavelength, which is often perceived as uneven waviness or rough surface imperfections. Macrotexture refers to pavement surface elevation changes on the order of 0.2-20 inches, which is in the range of maximum aggregate size.
  - **More coverage**. Open-graded material placed outside the travelled lanes can reduce tire-pavement noise propagation by its sound absorbing characteristics. (Sandberg & Ejsmont, 2002)

- Use texturing methods for PCC. In general, transverse tining (the most popular texturing method in the U.S.) produces the loudest surfaces with alternative methods such as longitudinal tining, carpet drags and diamond grinding producing quieter surfaces. (Sandberg & Ejsmont, 2002)
- Use fine surface treatments with aggregate on the order of 0.05 to 0.25 inches. This surface texture generally can also reduce noise. Examples cited in Sandberg and Ejsmont (2002) included a number of proprietary materials (e.g., EP-Grip, Epoxy-Durop, Pavetex, ITALGRIP, Novachip, Colsoft, Safedress, Masterpave, Tuffgrip, Hitex, Smatex, UL-M, Euroduit, Ultraflex, Microduit, Microflex, Microchape, Microvile, Microvia, Mediflex, Miniphone, Citychape, Colrug, Viaphone, Tapiphone) and showed noise reductions in the range of 1-6 dBA.

Example: Sample Calculation

An existing four-lane divided freeway is to be resurfaced with asphalt rubber open-graded friction course (ARFC). Ten lane-miles of freeway (5 in each direction) with 12-foot wide lanes are to be resurfaced. Also, two 14-foot wide off-ramps, each 2,000 feet (ft) long, and the existing 10-ft wide shoulders are to be resurfaced with dense-graded HMA (not a quiet pavement). The posted speed limit for the freeway is 65 mph while the posted speed limit for the off-ramps is 40 mph.

$$ARFC\ Area = (10\ \text{lane-miles}) \times \left(5{,}280\,\frac{\text{ft}}{\text{mile}}\right) \times (12\ \text{ft lanes}) = 633{,}600\ \text{ft}^2$$

$$Dense\ Graded\ HMA\ Area\ = (2{,}000\ \text{ft offramp})\times(2\ \text{offramps})\times(14\ \text{ft wide}) = 56{,}000\ \text{ft}^2$$

$$Total\ Area\ Paved\ =\ 633{,}600\ \text{ft}^2 + 56{,}000\ \text{ft}^2 = 689{,}600\ \text{ft}^2$$

$$\%\ of\ Surface\ with\ Quiet\ Pavement\ = \frac{633{,}600}{689{,}600} = 91.2\%$$

The area of the shoulders is excluded because it is not in the regularly trafficked lanes. OBSI tests after construction were done at 60 mph in accordance with AASHTO TP 76 on the inside northbound lane. The entire job consisted of one defined section. Within that section there were several curves but at least one straight stretch of over 500 ft. Results showed that the measured OBSI sound level on this section was 96.5 dBA. No tests were run on the ramps because they were not surfaced with quiet pavement and were excluded from the quiet pavement surface area calculation.

This project would earn 2 points because the minimum area requirement of 75% was met (91.2% was achieved) and the maximum sound level as measured by OBSI of 99 dBA was not exceeded.

Example: States with Quiet Pavements

Some of the largest users of quiet pavement in the U.S. are Arizona and California A few specific examples are:

- The Arizona DOT has placed over 4.2 million tons of rubberized asphalt (much of which is asphalt rubber friction course – ARFC – used for noise reduction) since 1988 (see map of 1988-2001 locations at: http://www.asphaltrubber.org/ari/Performance/ADOT_Projects_1998-2001.pdf). Surface lives are typically 10-12 years (Morris and Carlson, 2001) with noise typically in the 96-101 dBA range depending on conditions and age.
- Caltrans has placed a significant amount of open-graded friction course throughout the state. Specific locations of sections to be researched in the Caltrans Quieter Pavement Research Plan can be found at: http://www.dot.ca.gov/hq/esc/Translab/ope/QuieterPavements.html. The longest continually monitored quiet pavement in the U.S. is a section of I-80 near Davis, CA (http://www.dot.ca.gov/hq/env/noise/pub/IH80_davis_ogacpvmntwtudy_7yrrpt.pdf).
- The Washington State Department of Transportation (WSDOT) has several pavement surfaces under evaluation (http://www.wsdot.wa.gov/Projects/QuieterPavement). PCC locations are at: http://www.wsdot.wa.gov/NR/rdonlyres/5F022BDB-B9B3-437F-9016-2F1624EA0589/0/QuieterconcreteinWA.pdf . Open-graded HMA surfaces at: http://www.wsdot.wa.gov/Projects/QuieterPavement/Maps.htm.

Other states and areas also have active quiet pavement use and research programs including Georgia, Alabama, Florida, New Jersey, New Mexico, Minnesota, Kansas, United Kingdom, Belgium, the Netherlands, Denmark, Germany, Austria, Sweden and more.

POTENTIAL ISSUES

1. Without adequate prior testing on the surface course mix design, there is some risk that the constructed surface course will not meet the required maximum average noise levels for this credit.
2. In general, open-graded surface courses have shorter performance lives than traditional surfacing. Therefore, life-cycle costing of the roadway surface should be carefully considered and the potential for shorter service life should be considered.

3. While other methods may be successful, open-graded surface courses have been the most thoroughly researched and are reasonably well understood although there are still many unknowns.
4. Fine surface treatments can improve pavement surface texture, but in general these are surfaces used for primary purposes other than noise reduction. They often have noise reduction values associated with them but these values often have not been adequately tested or independently verified.
5. Measurement of noise “reduction” can be inconsistent. Usually noise reductions are reported in relation to (1) an established reference pavement, (2) a comparable dense-graded pavement, or (3) the previous pavement surface. In all cases these references are usually not well defined or their definitions vary from location-to-location. For instance, several European countries have standard reference pavements from which reference noise levels are measured, but these reference pavements vary from country-to-country. Because of this reference level dilemma, two pavements with the same measured tire-pavement noise may be reported as having entirely different noise reductions.

RESEARCH

This credit focuses on roadway noise from traffic that is generated from a roadway project after construction is complete. In particular, certain roadway surfacing materials can be used to reduce tire-pavement noise. For purposes of this credit, surfacing methods that reduce average tire-pavement noise below defined On-Board Sound Intensity (OBSI) levels (shown in Table PT-5.1) are defined as “quiet pavements.” It is worth noting that the aesthetic terms “quiet” and “noise” are based entirely on subjective human perceptions and depend on a number of variables. However, the decibel criteria used in this credit is necessary to distinguish and recognize roadway projects where teams intentionally approach long-term noise mitigation through pavement design.

Noise mitigation efforts and alternatives for minimizing temporary construction noise and long-term traffic noise are addressed in Project Requirement PR-5 Noise Mitigation Plan (NMP) and also generally in the first Project Requirement, PR-1 Environmental Review Process. Quiet pavements may be a viable strategy for operational noise mitigation for the roadway project, and may be included in both the NMP and documentation for the project environmental review process. Details and basic definitions of noise, how it is measured, and discussion of adverse human health impacts are provided in PR-5 and are not repeated here.

The following discussion focuses on details of roadway traffic noise and various methods of designing the pavement section to be quieter than conventionally designed pavements. Other traffic noise mitigation efforts, such as permanent sound walls or other common techniques, are not addressed by this credit.

Traffic Noise

Noise from a roadway is generated largely by the traffic activities taking place on the road. Noise generated from traffic depends on traffic volume, traffic speed, vehicle mix, engine types, tire types, vehicle condition, roadway geometry and physical features also depends on the characteristics of the surrounding environment such as topography, development and population density. Traffic noise can be disturbing either as a constant noise such as a steady stream of traffic such as from a highway or as single events such as passby of a truck, bus or even a car. Some typical noise levels you might expect if you were standing 50 feet away for different vehicle classes traveling at 55 mph (Michael Minor & Associates, n.d.):

- Passenger cars: 72-74 dBA
- Medium trucks: 80-82 dBA
- Heavy trucks: 84-86 dBA

Traffic noise generated from vehicles can be further categorized into four major sources (Bernhard et al., 2005): 1) engine and drive train noise, 2) exhaust noise, 3) aerodynamic noise and 4) tire-pavement interaction noise. Above about 30 mph tire-pavement noise is the predominant source (Bernhard & Wayson, 2005).

Pavement Surface and Noise Generation

Tire-pavement noise is influenced by both the tire and pavement type and condition (Sandberg & Ejsmont, 2002). While it may not be realistic to regulate tire types and condition for a particular project, pavement type can be specified in project design. Some of the characteristics of a pavement surface that can influence noise generation are (Sandberg & Ejsmont, 2002): texture of the surface, skewing (orientation of pavement texture), thickness of the pavement, porosity, tire-pavement adhesion and elasticity of the pavement surface. Also, as the pavement ages these characteristics often change which can cause changes in noise reduction properties (Munden, 2006).

Pavement Surface Noise Measurement

Tire-pavement noise can either be measured from the side of the road as a vehicle passes by or from a point (or points) very near a standard tire as it drives down the road. There are a number of variations of noise measurements that can be made in these two manners but In the U.S. the on-board sound intensity (OBSI) measurement method (Figure PT-5.2) enjoys growing popularity and is the measurement upon which this credit is based. This method is most useful for comparing pavement surfaces and is relatively portable and cost-effective. Since the OBSI method measures noise very near the tire, OBSI readings are not equivalent to noise readings alongside the roadway. However, the two can be roughly correlated (Figure PT-5.3). Additionally, OBSI measurements can vary by season (summer gives slightly lower values – Illingworth & Rodkin, 2005), weather (wet pavements are noisier) and location (measurements may vary along the roadway surface by about 2 dBA: Bennert et al., 2004).

Figure PT-5.2: OBSI measurement device (picture from Illingworth & Rodkin, Inc.)

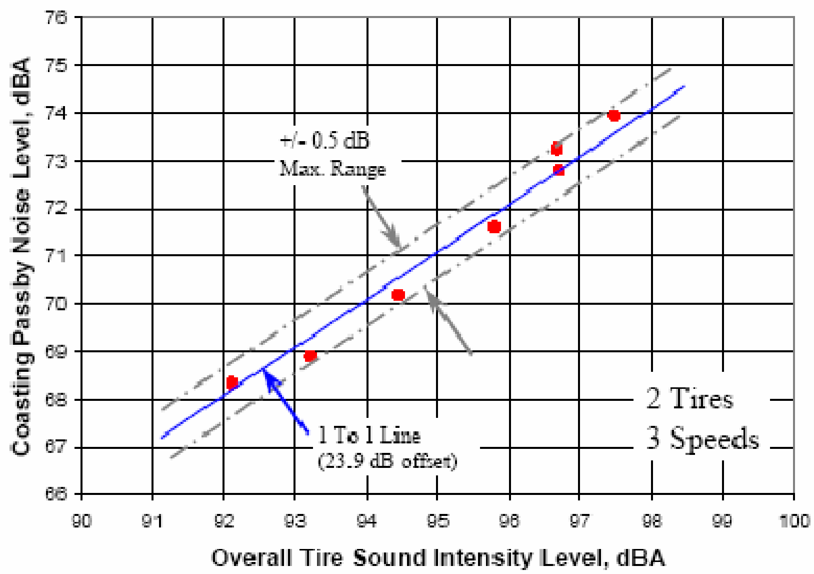

Figure PT-5.3: Relationship between pass-by (roadside) measurements and OBSI measurements for one particular study (graph from Donovan & Rymer, 2003).

Pavement Surface Design Options

A number of design options have been shown to produce lower tire-pavement noise. The primary considerations in choosing an option are (1) amount and duration of noise reduction, (2) pavement durability and (3) cost. This section briefly discusses major options available to the pavement designer.

Open-graded Quiet Pavements

The most recognized option is an open-graded mixture of HMA or PCC used for a pavement surface course. Open-graded refers to a general lack of fine aggregate material in the mixture resulting in interconnected air voids. As a rough rule-of-thumb, mixtures with an air void content above 15% can generally be considered to be open-graded and have interconnected air voids. The interconnected air voids tend to reduce noise by (1) reducing the generation of noise, and (2) absorbing generated noise in the air void structure of the mixture (Sandberg & Ejsmont, 2002).

Noise reduction ability is generally reported in the 3-9 dBA range but can vary widely depending upon the reference pavement used for comparison and environmental and geometric conditions. Figure PT-5.4 shows some noise levels measured in the U.S. and Europe.

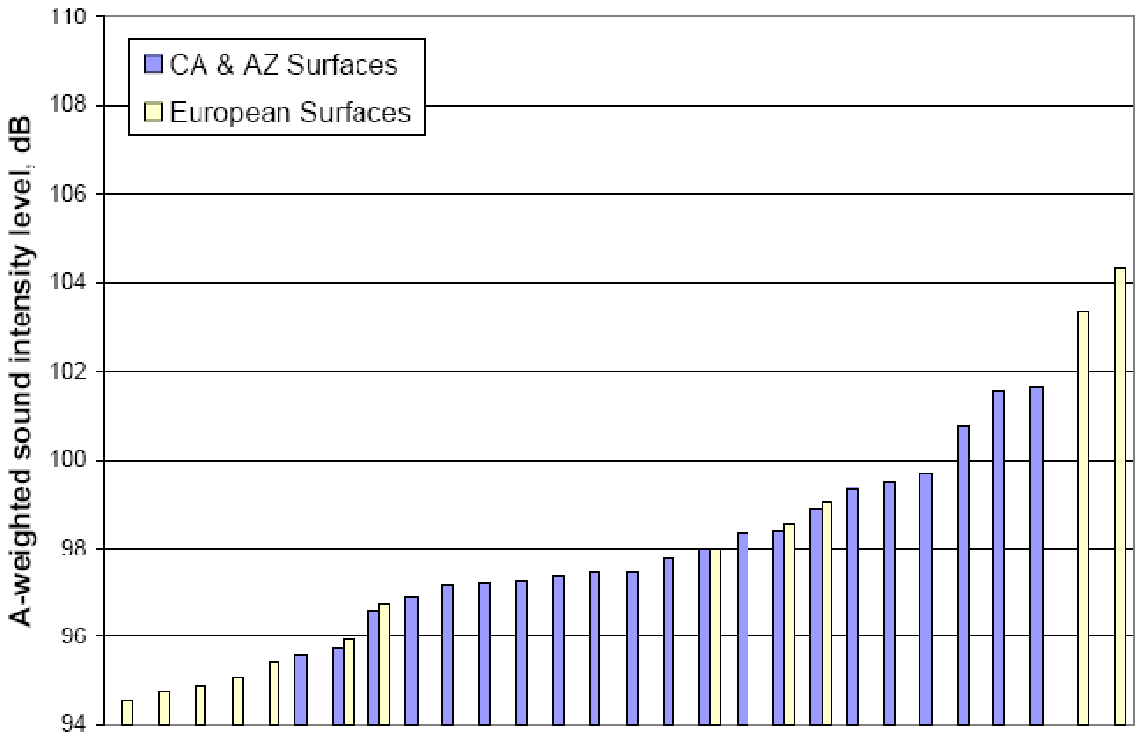

Figure PT-5.4: Comparison of sound intensity levels for various types of HMA open-graded surface courses in California, Arizona and Europe at 97 km/hr (60 mph). (From Donovan, n.d.)

In general, open-graded pavement surfaces have equal or shorter service lives than a standard pavement surfaces. Specifically, open-graded pavements may have maximum service lives in the 8 to 10 year range with the length of effective noise reduction being somewhat less. Bendtsen et al. (2008) report that the time history of quieting effect on noise levels of various European open-graded pavements varies widely but that on average one should expect noise level increases per year as seen in Table PT-5.2. Harvey et al. (2008) studied 54 California quiet pavement HMA surfaces and found that for any specific material older pavements were generally louder than younger ones. However, the older pavements still tended to produce less tire-pavement noise than similar non-quiet pavements.

Table PT-5.2: Overall Time History of Noise Increase (in dBA per year) of Pavement Service Time for Various Pavement-Traffic Conditions (From Bendtsen et al., 2008).

	Light Vehicles		**Heavy Vehicles**	
Surfacing	*High speed traffic*	*Low speed traffic*	*High speed traffic*	*Low speed traffic*
Dense HMA	0.1	0.1	0.1	0.1
Porous Open-graded HMA	0.4	0.9	0.2	-

Studded tire wear is a major concern in the longevity of open-graded pavements. Observations in Washington State indicate a near total loss in noise reduction in just over two years for an experimental asphalt rubber friction course (similar to those paved in Arizona) placed on I-5, and Bendtsen et al. (2008) also describe durability under studded tire traffic as a major concern noting that wear increases by a power of 2 with an increase in speed. Clogging of the interconnected air voids can also be a problem. For higher-speed facilities (on the order of 60 mph) a self-cleaning effect has been found (Ongel et al., 2008) resulting from the combination of water (contributed by rainfall) and a suction effect created by tire-pavement contact. However, on some pavements Ongel et al. (2008) did not see a cleaning effect where one was expected because of high-speed traffic. Finally, Chiba et al. (2008) found that in Japan snow removal equipment and tire chains tended to damage open-graded pavement surfaces and cause a loss of permeability after about 2 years. This seems to have led to an increase in noise level but measured noise levels after 6 years were still slightly below that for a conventional pavement surface.

Costs for open-graded pavement surfaces are typically reported as above those for traditional surfacing and can command a premium on a per-ton basis of 20-200% depending upon mix type, location and availability.

PCC Surface Texturing

Quiet pavement options for PCC can involve open-graded PCC but can also involve various means of texturing the PCC surface. Surface texturing can have a significant effect on tire-pavement noise and there are certain techniques that are better than others. Table PT-5.3 lists surface texturing and typical noise levels. Of note, transverse PCC joints also contribute significantly to noise levels.

Table PT-5.3: Typical PCC Surface Texturing and Average Noise Levels. Measured by Rasmussen et al. (2008).

Technique	Typical Noise Level	Notes
Transverse tining	104 dBA	Small, shallow grooves across the pavement surface transverse to the direction of traffic. The most popular means of PCC pavement texturing in the U.S.
Longitudinal tining	102 dBA	Small, shallow grooves across the pavement surface in line with the direction of traffic.
Carpet drag	100.5 dBA	Uneven texture created by dragging a piece of artificial turf across the pavement surface.
Diamond Grinding	99 dBA	Removes the surface with a gang-mounted spindle of saw blades. The resulting surface typically has a grooved appearance with the spacing and depth of grooves being controlled by the technique used.

PCC texturing life depends on traffic and the presence of studded tires. Tining can last in excess of 6 years (WSDOT, 2006) if no significant stud traffic exists while experience in Washington State has shown tining to last only 3-6 years (depending upon traffic levels) because of studded tire wear. The durability of carpet drag surfaces is not yet well understood. Finally, The American Concrete Pavement Association expects a typical diamond grind to last 14 years while results from Idaho (where studs are allowed) point to 10 years and results from California (where studded tire wear is insignificant) point to 16-17 years (Cotter, 2007).

PCC texturing is generally not as quiet as open-graded options but most techniques can achieve some noise reduction when compared to transverse tining. Rasmussen et al. (2008) point out that construction technique and details can also influence texturing effects on noise. Noise reduction strategies that rely on diamond grinding usually design the original pavement thicker than needed to compensate for the loss in thickness resulting from each grinding. While this technique works, it may not be sustainable beyond 2-3 grinding operations. Finally, studded tire wear can greatly reduce the life expectancy of any surface texturing technique.

With the exception of diamond grinding, PCC surface texturing is a standard procedure and thus, does not command a premium. Diamond grinding costs can vary widely depending upon quantity, aggregate hardness, contractor availability and geometry. Some example 5-year average costs provided during the open comment period for Version 1.0 are:

- Washington: \$9.45/yd^2
- Kentucky: \$2.67/yd^2
- Washington: \$2.27/yd^2

Other Techniques

Other surfacing techniques that are not engineered primarily for noise reduction have been shown to be somewhat quieter than conventional methods. Proprietary thin surfacing and stone matrix asphalt (SMA, which is a gap-graded mixture) are the two most commonly cited surfaces. Both work by creating a negative texture (where a majority of the surface texture is at the same height with small air void indentations) and/or using smaller maximum aggregate sizes (e.g., 3/8 inch or smaller in HMA). One concern with these types of surfacing methods is that they may lose their noise reduction capabilities more quickly than pavements specifically engineered to reduce noise. Harvey et al. (2008) found that Caltrans RAC-G mixes (a gap-graded mixture) increased noise levels over the first several years to where there were comparable to a typical 1/2-inch dense-graded HMA.

Prices for these surfacing methods vary widely. Proprietary mixtures are generally not predictable while SMAs may cost 20-30% more than traditional dense-graded HMA surfacing on a per-ton basis.

GLOSSARY

AASHTO	American Association of State Highway Tranportation Officials
dB	Decibel
dBA	A-weighted decibels
Ft	foot (feet)
HMA	Hot mix asphalt
Mi	mile(s)
Mph	miles per hour
Noise	Unwanted sound
OBSI	On-Board Sound Intensity
PCC	Portland cement concrete
SMA	Stone matrix asphalt

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