Principles and Practices of Quieter Pavements

a webinar sponsored by
TRB ADC40 Committee, Transportation-Related Noise and Vibration
TRB AFD90 Committee, Surface Properties – Vehicle Interaction

Wednesday, August 24, 2011
2:00 pm - 4:00 pm EDT (11:00 am - 1:00 pm PDT)

Designing and constructing quieter pavements is not difficult. In fact, it can be done using the same materials and techniques commonly used today. That said, there remain knowledge gaps in how this can be done effectively, and without compromising other important characteristics including safety, durability, and cost. This webinar will introduce the principles and practices of quieter pavements. It is intended to educate noise practitioners on the fundamentals of pavements, and pavement practitioners on the fundamentals of noise. Tire-pavement noise will be discussed, including where it comes from and how it is measured. Sources of traffic noise will also be described, along with related policy issues, both existing and forthcoming. The emphasis, however, will be on the current practices for designing and constructing quieter pavements. Specific alternatives will be described, along with guidance about how to quickly implement them into practice.

Learning Objectives

- Discuss some of the fundamentals of sound and texture.
- Describe research and policy directions related to the use of quieter pavements.
- Illustrate how quieter pavements are measured and interpreted.
- Categorize the mechanisms that lead to tire-pavement noise.
- Identify approaches for incorporating quieter pavement design and construction principles into current practices.
- Evaluate the role of a quieter pavement among other needs including safety, durability, and cost effectiveness.

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Agenda

- Welcome and introduction
- Setting the stage
  - Motivations for quieter pavements
  - Policy implications of using quieter pavements
- Noise and texture 101
  - Noise and texture fundamentals
  - Traffic noise
  - Tire-pavement noise
  - Measurement techniques
- Principles of a quieter pavement
  - Texture
  - Uniformity
- Quieter pavement design and construction practices
- Ongoing activities
- Questions & answers

Presenters

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Principles and Practices of Quieter Pavements
**Sponsorship and Support**
- TRB ADC40 and AFD90
- Federal Highway Administration
- Tire-Pavement Noise Research Consortium, TPF-5(135)

**Principal Instructors**
- Robert Otto Rasmussen, PhD, INCE, PE (TX)
- Paul R. Donavan, ScD, INCE
- Judy Rochat, PhD, INCE
Learning Objectives

At the conclusion of this workshop, you should be able to:

- Discuss some of the fundamentals of sound and texture.
- Describe research and policy directions related to the use of quieter pavements.
- Illustrate how quieter pavements are measured and interpreted.
- Categorize the mechanisms that lead to tire-pavement noise.
- Develop an approach for incorporating quieter pavement design and construction principles into their current practices.
- Evaluate the role of a quieter pavement among other needs including safety, durability, and cost effectiveness.
Workshop Agenda

- Welcome and introduction
- Setting the stage
- Noise and texture 101
- Principles of a quieter pavement
- Quieter pavement design and construction practices
- Final thoughts
- Questions & answers
Pavement Surface Characteristics (PSC)

- Smoothness
- Friction
- Tire-pavement noise
- Splash and spray
- Surface drainage
- Light reflection
- Rolling resistance
- Tire wear
- Vehicle wear
PSC – Texture

Roughness

Megatexture

Macrotecture

Microtexture
Do Friction and Noise Relate?

Source: Iowa State University
Why noise is important in Europe, Japan, and elsewhere

- **Density**
  - Population
  - Greater exposure to noise

- **Public attitude**
  - Noise pollution
  - Sustainability

- **Political motivation**
  - European Union (EU)
  - World Health Organization (WHO)
International Awareness

- Overall noise policy for all EU countries using integrated strategies
  - Noise barriers
  - Source controls
- All countries to map transportation noise by 2007, and develop a plan to address critical areas
- Noise annoyance surveys are used to determine levels for roadway noise
- Several countries have established abatement guidelines and limit values
U.S. Noise Policy

Building a new road or reconstructing a road?

- Noise analysis required for projects receiving federal aid
Federal-aid project

Apply 23 CFR 772
Procedures for Abatement of Highway Traffic Noise and Construction Noise

- Need to conduct noise impact analysis
- Impact identified ⇒ need to consider noise abatement
- Noise abatement can not include use of quieter pavement, except with special approval by FHWA

This does not prevent the use of quieter pavements
U.S. Noise Policy

Noise impact determination

1. Visit site
2. Measure existing noise
3. Using the FHWA Traffic Noise Model® (TNM®), model site and predict noise levels in nearby communities
4. Noise impact?
   - Compare predicted results to Noise Abatement Criteria (NAC)
     - Federal – approach or exceed 67 dBA $L_{eq}$ in residential areas
     - State & Local
   - Compare predicted results to existing noise
     - Substantial increase defined as 5-15 dB above existing
U.S. Noise Policy

Considering noise abatement

Must be evaluated for feasibility and reasonableness

Feasible?

- Must achieve at least 5 dB reduction
  - Used to determine number of benefitted receptors
- Possible to design and construct

Reasonable?

- Viewpoint of residents
- Cost effectiveness
- Must meet noise reduction design goal (7-10 dB)
U.S. Noise Policy

Abatement options

- Noise barriers
- Traffic management measures
- Alteration of horizontal or vertical alignments
- Acquisition of property
- Noise insulation
FHWA Traffic Noise Model (TNM)

- Current version: 2.5

- Vehicle noise sources based on field-measured database (REMEL)

- Models different pavement types
  - PCC, DGAC, OGAC
  - Average – required by policy

- Models effects due to …
  - terrain elevation changes
  - ground types
  - rows of buildings
  - dense vegetation

- Graphically interactive noise barrier design
TNM Pavement Effects Implementation (PEI) Study

- FHWA and Volpe Center assessing options for implementing in TNM the effects of pavement on highway traffic noise

- Investigating implementation of...
  - new pavement-specific vehicle noise emission (REMEEL) data
  - tire/pavement noise source adjustments using pavement-specific on-board sound intensity (OBSI) data
  - pavement-specific sound absorption (EFR) values
TNM Pavement Effects Implementation (PEI) Study

- Developed special research version of TNM
- Tested implementation ideas with preliminary data
- Results validate methodologies tested

![Graph showing LAeq5min (dBA) vs. One-third octave band center frequency (Hz)]

- Measured Data
- TNM Average
- TNM Adjusted (OBSI by Road Type)
- TNM Adjusted (OBSI by Specific Road)
TNM Pavement Effects Implementation (PEI) Study

Future considerations

- Further research needed to refine implementation methodologies
- Need large database of pavement-specific OBSI and EFR values
- Implement array of pavements in future version of TNM
- Policy implications
Using Quieter Pavement

For noise abatement – special FHWA approval

Quiet Pavement Pilot Program (QPPP)
- Allows states to consider pavement as noise abatement
- Arizona is only state with QPPP

![Graph showing noise levels over time for different pavement types](image-url)
Using Quieter Pavement

General use
- At discretion of State & Local authorities
  - Can even be part of federal-aid project, as long as use is not for noise abatement
- FHWA encourages States to participate in Quiet Pavement Research
  - Determine noise benefits for specific pavements
  - Determine longevity of noise benefits
  - Several States already conducting research

For noise impact determination – special FHWA approval
- Using pavement types currently in TNM

Note: Louder pavements should also be examined and considered for use in noise impact determinations
Further Information

- FHWA noise website
  http://www.fhwa.dot.gov/environment/noise/

- TRB meetings
  Noise & Vibration Committee
  www.adc40.org

  Surface Properties – Vehicle Interaction Committee
  http://sites.google.com/site/trbcommitteeafd90/
Workshop Agenda

- Welcome and introduction
- Setting the stage
- Noise and texture 101
- Principles of a quieter pavement
- Quieter pavement design and construction practices
- Final thoughts
- Questions & answers
Sound is anything we can hear... and more!

Noise is undesirable Sound!
Sound waves are small air pressure changes.
Units of pressure are typically Pascal.

Source: Brüel & Kjaer
## Sound Amplitude – Loudness

<table>
<thead>
<tr>
<th>Change in Sound Level ($\Delta$ dB)</th>
<th>Change in Loudness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 3 dB</td>
<td>“Just perceptible” change</td>
</tr>
<tr>
<td>5 dB</td>
<td>“Noticeable” change</td>
</tr>
<tr>
<td>10 dB</td>
<td>“Twice” (or $\frac{1}{2}$) as loud</td>
</tr>
<tr>
<td>20 dB</td>
<td>“Four times” (or $\frac{1}{4}$) as loud</td>
</tr>
</tbody>
</table>

Source: Brüel & Kjaer

True only for the same sound!
Example:
Period = 0.001 sec
Frequency = 1000 Hz
Wavelength = 1.1 ft.

Note: Sometimes termed “pitch”
Audible Range

Source: Brüel & Kjaer

Frequency (Hz)

1 10 100 1000 10,000 100,000
Common Sounds and their Frequencies

Source: Brüel & Kjaer
Sound Generation and Propagation

Doubling the traffic volume =

Is it 65 or 68?

Source: Arizona DOT
Sound Generation and Propagation

Environmental Effects

Wind

Sound

Ground

Shadow Zone
Basic Sound Measurement

- Windscreen
- Microphone & Preamplifier
- Sound Level Meter
- Recording Device (Optional)
### Basic Sound Analysis

#### 1/3 Octave Levels

![Graph showing on-board sound intensity levels across different frequencies (500 Hz to 5000 Hz). The levels range from 40 to 110 dBA.](image)

- Frequency (Hz): 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000
- On-Board Sound Intensity Level (dBA): 40, 50, 60, 70, 80, 90, 100, 110

Source: Transtec CPSC
Total Level

Basic Sound Analysis

Overall OBSI Level: 106.0 dBA

Source: Transtec CPSC
The Listening Experience

Is it 65 or 68?
The Listening Experience – Frequency

- 250 Hz
- 500 Hz
- 1000 Hz
The Listening Experience – Frequency

- 250 Hz
- 500 Hz
- 1000 Hz
The Listening Experience – Frequency

- 250 Hz
- 500 Hz
- 1000 Hz
The Listening Experience – Frequency

- Ears are less sensitive to very low frequencies and extremely high frequencies.
- Human ears mechanically “filter” sounds of different frequencies.
- Mathematically, we “filter” objective sound measurements to roughly predict the subjective (human) response using “weighting networks.”
The Listening Experience – Frequency

Sound Pressure Level Adjustment (dB)

-60 -40 -20 0

Frequency (Hz)

10 20 50 100 200 500 1 k 2 k 5 k 10 k 20 k

Linear

A  B  C  D

A-weighted – moderate sounds
(most often used, but developed for < 55 dB)

B-weighted – intense sounds (55-85 dB typ.)

C-weighted – very loud sounds (>85 dB typ.)

D-weighted – “noisiness” measure
(sometimes used for aircraft noise)

Source: Brüel & Kjær
The Listening Experience – Amplitude

- dB
- 0
- -3
- -5
- -10

- Lp
- Frequency

- p
- Frequency

- Lp
- Frequency

- Lp
The Listening Experience – T/P Noise

Tire-pavement noise:
- Porous asphalt
- Longitudinally tined PCC
- Dense-graded HMA
- Uniform transverse tined PCC

<table>
<thead>
<tr>
<th>Third-Octave Frequency (Hz)</th>
<th>OBSI Level (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>70</td>
</tr>
<tr>
<td>630</td>
<td>80</td>
</tr>
<tr>
<td>800</td>
<td>90</td>
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<tr>
<td>3150</td>
<td>60</td>
</tr>
<tr>
<td>4000</td>
<td>50</td>
</tr>
<tr>
<td>5000</td>
<td>40</td>
</tr>
</tbody>
</table>
The Listening Experience – T/P Noise

Tire-pavement noise:

- Porous asphalt
- Longitudinally tined PCC
- Dense-graded HMA
- Uniform transverse tined PCC

Overall Level: 97 dBA
The Listening Experience – T/P Noise

Tire-pavement noise:
- Porous asphalt
- Longitudinally tined PCC
- Dense-graded HMA
- Uniform transverse tined PCC

Overall Level: 101 dBA
The Listening Experience – T/P Noise

Tire-pavement noise:
- Porous asphalt
- Longitudinally tined PCC
- Dense-graded HMA
- Uniform transverse tined PCC

Overall Level: 101 dBA
The Listening Experience – T/P Noise

Tire-pavement noise: Porous asphalt
Longitudinally tined PCC
Dense-graded HMA
Uniform transverse tined PCC

Overall Level:
106 dBA
Vehicle Noise – Sources

Overall Vehicle Noise

- Propulsion
- Aerodynamic
- Tire-pavement interaction
Traffic Noise – Mix

One truck traveling at 60 mph sounds as loud as….

10 cars traveling at 60 mph

Source: FHWA TNM
When Congress allowed states to raise speed limits, highways got noisier.

- A car at 65 mph is 3 dB louder than a car at 55 mph.
- A truck at 65 mph is 2 dB louder than at 55 mph.
Tire Noise – Tire Components

Tradeoffs:
- Wet handling
- Wet traction
- Hydroplaning
- Rolling resistance
- Tread wear
- Dry handling
- Snow
- Ride comfort
- Pattern noise
- Road noise
- “Looks”
Tire Noise – Hammer Mechanism

- Highway texture and tread block induce radial vibrations of the tread block and the tire carcass
- Like a rubber hammer
- Important at low & mid frequencies

Make impacts soft and random

Source: Purdue SQDH, Ulf Sandberg
“Stick-slip” between tread blocks and surface creates tangential motion

Causes squeaks and squeals – high frequency

Like a squeaky sneaker on a basketball court

Increase local friction and increase surface roughness

Source: Purdue SQDH, Ulf Sandberg
Tire Noise – Pipe Mechanism

- Channels in tire footprint act like organ pipes, amplifying source
- Radiate sound out from channel
- Mid-frequency effect

Source: Purdue SQDH, Ulf Sandberg
On-Board Sound Intensity (OBSI) Method

Standardized as AASHTO TP 76
Wayside Noise Testing

- Statistical Isolated Pass-by (SIP) – AASHTO TP 98
- Continuous-Flow Traffic Time Integrated Method (CTIM) – AASHTO TP 99
- Controlled Pass-by (CPB)

Diagram showing:
- Radar
- Microphone
- Recording system
- Weather station
Comparing Noise Measurements

- **Uniform Transverse Tining**
- **Two Measurements:**
  - Near Field (OBSI) 106 dBA
  - Wayside (SIP) 77 dBA
Workshop Agenda

- Welcome and introduction
- Setting the stage
- Noise and texture 101
- Principles of a quieter pavement
- Quieter pavement design and construction practices
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- Questions & answers
3 Commandments

...for a Quieter Pavement
Thou shalt have Texture...

be it small and negative!

Bad

Good
Sand Patch Method

Texture Testing

Circular Track Meter

RoboTex
Exposed Aggregate Concrete

Positive Texture
Negative Texture

Tined Concrete

Negative Texture
Positive Texture

Source: Transtec
Smooth Rolled OGFC

Negative Texture

Source: Ulf Sandberg
Texture versus Noise

- Shallow: > 10 mm
  - Happy smiley
- Deep: > 10 mm
  - Sad smiley
- Shallow: < 10 mm
  - Sad smiley
- Deep: < 10 mm
  - Happy smiley
Thou shalt have High Porosity!
Porosity

- Pervious Concrete
- Dense Concrete
- Porous Asphalt
- Dense-Graded Hot-Mix Asphalt
Thou shalt have Low Stiffness!
Stiffness

Good luck !!!
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Don Leatherman's
NASCAR Top 5
Quieter Pavements
Longitudinally Tined Concrete
Longitudinal Tining

- 3/4” spacing most common
- 1/16” to 3/16” deep
- Minimize “waviness” through automated control
- Adequate cross slope provides necessary surface drainage
Stone Matrix Asphalt

Source: Bo Nash
- Gap-graded aggregate
- Manufactured sands and mineral filler
- Asphalt binder typically modified

Smaller stone mixtures quieter than more conventional (larger stone) SMA

Source: University of Washington
Drag Texture

- **Burlap drag**
  - Commonly used for slower speeds

- **Artificial turf drag**
  - Some high-speed facilities

Source: ACPA
Rubberized Asphalt
Rubberized Asphalt

“A blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles” – ASTM D 8-88

- Noise reduction first reported in Europe
- Common practice in Arizona, California, and Texas
- Typically uses 15-20% rubber
- Arizona mixture is primarily ¼ in. aggregates
Open-Graded Asphalt

Source: North Central Superpave Center
Open-Graded Asphalt

- Open-graded aggregate
- Thick asphalt binder coating
- Array of tortuous pores
- Dissipates energy through friction
- Reduced surface area and stick-slip generation
- Reduces air pumping
- Reduces horn effect
- Smaller stone mixtures are quieter
- Double layer porous may be more beneficial

Dutch: 20% porosity

Source: North Central Superpave Center, Purdue SQDH, DWW (NL)
Diamond saw blades cut parallel grooves

- Improves smoothness
- Increases friction
- Reduces tire-pavement noise

Source: APCA, IGGA
Diamond Grinding

- Can remove 1/8” to 3/4” from surface
- Cutting head has ~ 60 blades/ft.
- Blade spacing and grinding rate a function of coarse aggregate type

Source: IGGA
Variability in the Pavement leads to Variability in Tire-Pavement Noise
VARIABILITY

From project to project, and within a given project.
Variability – Concrete Pavements

A-weighted Overall OBSI Level, 60 mph, SRTT (dB ref 1 pW/m²)

Probability Density

- Diamond Grinding
- Drag
- Longitudinal Tining
- Transverse Tining
Long. Tining

- 99 dBA
  - Colorado

- 99 dBA
  - Iowa

- 105 dBA
  - New York

- 104 dBA
  - Iowa
Variability – HMA Pavements

ISO Pass-By Noise Levels (dBA)

- Thin OGFC 6 mm
- Thin OGFC 10 mm
- Thin SMA 6 mm
- Ultrathin DGA 6 mm
- Thin OGFC 14 mm
- DGA 10 mm
- Ultrathin DGA 10 mm
- Cold-Applied Slurry Surface
- Thin SMA 10 mm
- Surface Dressing Brushed Concrete
- DGA 14 mm
- Ultrathin DGA 14 mm

Source: LCPC (France)
Variability – Within a Project

On-Board Sound Intensity Level (dBA)

44-ft. Moving Average

Distance (ft.)

Longitudinal Tined Concrete Pavement

Dense-Graded HMA Pavement

Source: National Concrete Pavement Technology Center
Design and Construction Guidelines

- Avoid (flatten) texture at intervals > 1”
- Avoid smooth (flushed or polished) surfaces
  - Some fine texture (< ¼”) required
- Texture should be negative
  - Point down (voids), not up (chips)
- Texture should be oriented longitudinally

Bad

Good
Segregation

Source: University of Washington
Texturing Equipment
Auto Float
Roller Checking (Excess Deflections)
Washboarding

photo courtesy of NCAT
Grooves
↓  ↓
↑  ↑
Lands

Diamond Grinding

Fins
Tire-Pavement Noise Specifications

Different Approaches
- Methods Specifications
- End-result Specification
- Do NOT combine prescriptive and end-result !

Staged Implementation
- Lessons learned from smoothness specifications
- Proceed with care – we all have a lot to learn
- Do not repeat the same mistakes !

Innovative Technology
- Equipment automation
- Real-time feedback and control
Visualization
Tire-Pavement Noise Visualization

- Efficient Measurements with OBSI
- Inventory Assessment
- Pavement Management
- Public Outreach
- Project Screening
Visualization
Visualization
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Selecting Pavement Type and Texture

- Look at the Functional Demands
- Match to the Functional Supply from a given pavement type and texture
- Friction, Noise, and Smoothness
Ongoing Activities

FHWA
- Tire-Pavement Noise TWG

Pooled Fund
- TPF-5(135) – Tire/Pavement Noise Research Consortium
- TPF-5(139) – PCC Surface Characteristics

State DOT
- Quieter Pavement Research
- CA, CO, KS, MN (Mn/ROAD), NJ, TX, VA, WA, etc.

NCHRP
- Project 1-44 – Measuring Tire-Pavement Noise at the Source
- Project 8-56 – Truck Noise-Source Mapping
- Project 10-76 – Evaluating Pavement and Barrier for Noise Mitigation