Concrete Pavement Surface Characteristics

Session 1: Welcome and Introduction

Presented by:
Robert Otto Rasmussen, PhD, INCE, PE (TX)
Paul D. Wiegand, PE (IA)
Dale S. Harrington, PE (IA)

Concrete Pavement
Surface Characteristics

Workshop Agenda
- Welcome and introduction
- Setting the stage
- Noise and texture 101
- Fundamentals of improved pavement surface characteristics
- CPSCP database
- Design and construction guidance
- Guide specifications
- Selecting the right texture
- Training and discussion

Workshop Team
- Sponsorship and Support
  - Iowa DOT, Caltrans, Texas DOT, NYSDOT, Mn/DOT, WisDOT, WSDOT
  - FHWA
  - ACPA, IGGA
- Principal Instructors
  - Robert Otto Rasmussen, PhD, INCE, PE (TX)
  - Paul D. Wiegand, PE (IA)
  - Dale S. Harrington, PE (IA)
- Workshop Development and Credit
  - Richard Sohaney
  - Paul Donavan, ScD

Workshop Goals
- At the end of this workshop, you will not be able to:
  - Conduct on-board sound intensity testing
  - Operate a texture/cure machine
- But if we are successful together, you will:
  - Know that building a safe, smooth, and quieter concrete pavement is easier than you might think
  - Appreciate the complexity of the issues and the need to work together to seek out solutions

CPSCP 101 Workshop Objectives
- To educate pavement practitioners on the fundamentals of pavement surface characteristics including noise, texture, friction, and smoothness.
- To convey the fundamentals of measuring and interpreting pavement surface characteristics.
- To teach through interactive demonstrations and listening experiences.
- To examine current practices for designing and constructing safer, smoother, and quieter concrete pavements.
- To inform about new specifications and guidance to improve concrete pavement surface characteristics.

Workshop Goals
- We are not here to lecture!
- Our goal is to describe this complex topic in simple terms...
  - ...giving you the basic knowledge you will need if and when the time comes.
- We need to hear from you too... as your concerns, questions, and stories will help others. We all are on a similar journey!
Concrete Pavement Surface Characteristics

Session 2: Setting the Stage

Presented by:
Robert Otto Rasmussen, PhD, INCE, PE (TX)
Paul D. Wiegand, PE (IA)
Dale S. Harrington, PE (IA)

Pavement Surface Characteristics (PSC)
- Smoothness
- Friction
- Tire-pavement noise
- Splash and spray
- Surface drainage
- Light reflection
- Rolling resistance
- Tire wear
- Vehicle wear

PSC – Texture
- Rolling Resistance
- Ride Quality
- Wet Weather Friction
- Dry Weather Friction
- Splash and Spray
- Tire Wear
- Vehicle Wear

PSC – Durability, Maintenance, and Cost
- PSC change over time
- Sometimes PSC improve, but in most cases, deteriorate
- Material, traffic, and climatic factors
- Maintenance and restoration of PSC
  - Diamond grinding
  - Concrete overlays

PSC – Tires
- Surface characteristics often dependent on the tire too
- Numerous properties of the tire affect noise, safety, etc.
- The tire industry optimizes for the driver... not those on the side of the road
Sound versus Noise

**Sound** is anything we can hear... and more!

Noise is undesirable **Sound**!

### Sound Amplitude

- Sound waves are small air pressure changes
- Units of pressure are typically Pascal

### Sound Amplitude – Loudness

<table>
<thead>
<tr>
<th>Change in Sound Level (Δ 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 ½) as loud</td>
</tr>
<tr>
<td>20 dB</td>
<td>“Four times” (or ¼) as loud</td>
</tr>
</tbody>
</table>

True only for the same sound!

### Frequency

\[
\text{Period} = \frac{1}{\text{Frequency}} \quad \text{Wavelength} = \frac{\text{Period} \times \text{Speed of Sound}}{\text{Frequency}}
\]

Note: Sometimes termed “pitch”
Sound Generation and Propagation

Every "sound" includes 3 things:
- Source
- Propagation medium (air)
- Receiver
- Sound levels are calculated from these
- Obstacles make calculations more complicated

Ground Effects

Hard Ground

Soft Ground
Sound Generation and Propagation

Environmental Effects

Wind

Sound

Shadow Zone

Ground

---

Basic Sound Measurement

Sound Pressure Signal

Sound Pressure (Pa)

Time (sec)

---

Basic Sound Analysis

1/3 Octave Levels

On-Board Sound Intensity Level (dBA)

Frequency (Hz)
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

- 250 Hz
- 500 Hz
- 1000 Hz
- 4000 Hz
- 8000 Hz
- 16,000 Hz

Sound Pressure Level Adjustment (dB)

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 – Annoyance
- Same sound level (dBA)...
  - Pink noise vs. pure tones
  - Pure tone vs. modulated tone

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

Vehicle Noise – Crossover Speed
<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Crossover Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>10-25</td>
</tr>
<tr>
<td>Trucks</td>
<td>35-50</td>
</tr>
</tbody>
</table>

Traffic Noise – Speed
- 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 – Pop Quiz**

Which is Noisier?

A  B  C  D  E

**Tire Noise – Squeaker Mechanism**

- "Stick-slip" between tread blocks and surface creates tangential motion
- Causes squeaks and squeals – high frequency
- Like a squeaky sneaker on a basketball court

**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

**Tire Noise – Pipe Mechanism**

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

**Tire Noise – Clapper Mechanism**

- Air is pumped out at the entrance and exit of contact patch
- Depends on tread passages and pavement porosity
- Important at high frequencies

**Tire Noise – Horn Mechanism**

- Horn shape amplifies sound produced by air pumping and tread vibration
- Directs sound outward
- Dependent on width of tire and acoustical characteristics of pavement
- High frequency
- Fairly significant effect

*Source: Purdue SQDH, Ulf Sandberg*
Tire Noise – Pop Quiz

Which is Noisier?

A B C D E

Increasing Noise:
9 to 10 dBA
Total Range

Friction Testing – Skid Trailer
- Measures wet friction at one speed at a time
- Standardized in ASTM E 274
- ASTM E 501 (ribbed) or E 524 (smooth) tire
- Smooth tire allows for differentiation of macrotexture effects on friction

Friction Testing – DFT
- Friction as a function of speed – ASTM E 1911
- Wet friction on small rubber pads 50 mph
- Coupled with macrotexture, allows prediction of International Friction Index (IFI) and correlated relationships to E 274 trailer

Texture Testing
- Sand Patch Method
- Circular Track Meter

Texture Testing
- RoboTex (LMI RoLine)

OBSI Noise Testing
- On-Board Sound Intensity (OBSI) Method
  - Developed by GM in late 1970s
  - Enhanced in 1980s and 1990s by Dr. Paul Donavan
  - Standardized as AASHTO TP 76
Wayside Noise Testing
- Statistical Isolated Pass-by (SIP)
- Continuous-Flow Traffic Time Integrated Method (CTIM)
- Controlled Pass-by (CPB)

In-Vehicle Noise Testing
- Standardized by SAE J1477 and ISO 5128
- Same vehicle can be used for near field, controlled pass-by, and in-vehicle noise

Comparing Noise Measurements
- Uniform Transverse Tining
- Three Measurements:
  - Near Field (OBSI) 106 dBA
  - Wayside (SIP) 77 dBA
  - In-Vehicle 66 dBA

Texture versus Noise
- > 10 mm: Shallow
- < 10 mm: Deep
Concrete Pavement Surface Characteristics

Session 4: Fundamentals of Improved Pavement Surface Characteristics

Presented by:
Robert Otto Rasmussen, PhD, INCE, PE (TX)
Paul D. Wiegand, PE (IA)
Dale S. Harrington, PE (IA)

Concrete Pavement Design
- Jointed concrete pavement (JCP)
- Continuously reinforced concrete pavement (CRCP)
- Precast concrete pavement

Joints can affect noise, keep them:
- Narrow
- Adequate load transfer

Concrete Pavement Construction
- Texturing, curing, and jointing
- Uniformity!
Concrete Pavement Preservation

- Preventive Maintenance
  - Joint / crack sealing
  - Dowel bar retrofit
- Repairs
  - Full depth repair
  - Partial depth repair
  - Cross-stitching
- Better Practices
- Uniformity!

Thou shalt have Texture...
be it small and negative!

Bad

Good

Concrete Pavement Preservation

- Functional resurfacing
  - Diamond Grinding
  - Thin concrete overlays
- Uniformity!

Exposed Aggregate Concrete

Positive Texture

3 Commandments

...for a Quieter Pavement

Texture

Tined Concrete

Negative Texture
Stiffness

Yah... good luck with all that !!!

Transverse Tining

- For noise, preferred spacing is 1/2” with slight randomization
- Uniform tining can cause whine
- Random tining with 1” or greater spacing can be very loud
- 1/16” to 3/16” deep
- Control depth across width of tining rake
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

Drag Texture

- Burlap drag
  - Commonly used for slower speeds
- Artificial turf drag
  - Some high-speed facilities

Diamond Grinding

- Diamond saw blades cut parallel grooves
- Improves smoothness
- Increases friction
- Reduces tire-pavement noise
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

Lesson Learned
There is a lot of:
VARIABILITY
Variability from project to project, and variability within a given project.

Concrete Pavement Surface Characteristics
Session 5: CPSCP Database

Concrete Pavement Surface Characteristics

In 5 years, 1600 unique textures have been tested
- Transverse Tining (incl. skewed and cross-tined)
- Longitudinal Tining (incl. sinusoidal)
- Diamond Ground
- Grooved (longitudinal, transverse)
- Drag (Burlap, Turf, Broom, Belt, Carpet)
- Shot Peened
- Exposed Aggregate
- Porous (Pervious) Concrete
- Milled
- HMA and Surface Treatments

Hundreds of miles in 20 States and 6 Countries

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

Job-to-Job Variability: Diamond Grinding

Source: IGGA
Job-to-Job Variability: Drag

Job-to-Job Variability: Longitudinal Tining

Job-to-Job Variability: Transverse Tining
**Acoustical Durability**

- CDOT Rifle 2006
- CDOT Rifle 2007
- CDOT Rifle 2007 (Center Lane)

**Joints**

- Section 203E (GA), AM Measurements - Diamond Grooves/Transverse Grooved Bridge Deck

**Joints**

- Joint deterioration increases joint noise
- Wide, spalled, and faulted joints can reduce the benefit of a quieter texture
- If texture is low noise, joint noise can more noticeable
- Joint noise can increase overall noise level (sometimes > 1dBA)
Concrete Pavement Surface Characteristics

Session 6: Design and Construction Guidance

Presented by:
Robert Otto Rasmussen, PhD, INCE, PE (TX)
Paul D. Wiegand, PE (IA)
Dale S. Harrington, PE (IA)

Design and Construction Guidelines

- Avoid (flatten) texture at intervals > 1"
- Avoid smooth (floated or polished) surfaces
  - Some fine texture (< ¼”) required
- Texture should be negative
  - Point down (grooves), not up (fins)
- Texture should be oriented longitudinally
- If transverse, texture should be closely spaced and randomized

Bad

Good

Concrete

- Strong and durable mortar
  - Mix optimized for placement, finishing, curing
- Siliceous sands for durability and friction
- For diamond grinding: hard, durable, and polish resistant coarse aggregate is ideal
- For tined and drag textures: adequate and consistent depth of mortar near the surface

Segregation
Texturing

Texturing Equipment

Joints
- Can affect noise levels and annoyance
- Narrow, single-cut joints preferred
  - Avoid widened (reservoir) cuts
- Avoid faulted joints
  - Design or retrofit adequate load transfer
- Avoid protruding joint sealant
- Avoid spalled joints
  - Design, materials selection, and construction

Placement

Placement

Auto Float

Concrete material
- Durable mortar fraction – adequate “cream” to allow shaping of grooves
- Siliceous sand
- Strong and dense paste – low w/c

Equipment
- Automated texture/cure machine with uniform depth and alignment
- Minimize vibrations of paver and at tining rake

Construction technique
- Pre-texture with drag (burlap or turf)
- Curing – timing and effectiveness very important
- Clean/replace tines when worn
- Minimize material displacement

Tining

Concrete material
- Durable mortar
- Siliceous sand
- Strong and dense paste – low w/c

Equipment
- Automated texture/cure machine with uniform depth and alignment
- Minimize vibrations of paver and at tining rake

Construction technique
- Pre-texture with drag (burlap or turf)
- Curing – timing and effectiveness very important
- Clean/replace tines when worn
- Minimize material displacement

Drag

Concrete material
- Durable mortar
- Siliceous sand
- Strong and dense paste – low w/c

Drag material
- Artificial turf (approved by FHWA)

Construction technique
- Curing is paramount!
- User proper type of turf to ensure depth
- Clean/replace drag material when texture becomes shallow
- Minimize vibrations of paver
Diamond Grinding

- Concrete material
  - Check for potential of early wear/polishing of aggregate
  - Check that aggregates will wear evenly
- Grinding head
  - Select blade and spacer width based on aggregate/concrete hardness – no “magic” combination
  - Minimize jagged “fins”
- Equipment operation
  - Minimize excess equipment vibration
  - Check that depth control wheels and bogies are true (round)
  - Remove existing texture and avoid “holidays”

Quality Assurance

Measuring Texture
Measuring Texture

- Sand Patch (ASTM E 965)
- Calculates Mean Texture Depth (MTD)

RoboTex
- LMI RoLine height sensor, inertial referencing
- GPS, DMI encoder, video log

Predicting Noise from Texture

Transverse Tining
\[ \text{OBSI} = \frac{L_{tx}}{L_{tx,160} + L_{tx,25} + R_k} \]

Longitudinal Tining
\[ \text{OBSI} = \frac{L_{tx}}{L_{tx,40}} \]

Diamond Grinding
\[ \text{OBSI} = \frac{L_{tx} + 63 + 50 + 40 + \text{Skew}_{TR}}{50 + 40 + \text{Skew}_{TR} + R_k} \]

Drag
\[ \text{OBSI} = \frac{L_{tx}}{L_{tx,50} + L_{tx,40}} \]

- \( L_{tx} \) per ISO/CD 13473-4 (Draft)
- \( R_k \), \( \text{Skew}_{TR} \) per ASME B46.1

• LMI per ISO/CD 13473-4 (Draft)
• \( R_k \), \( \text{Skew}_{TR} \) per ASME B46.1

- +1 dBA

Noise can not be Predicted by Texture Depth !!!

Monitor Texturing Operations
Monitor Texturing Operations

Concrete Pavement Surface Characteristics

Session 7: Guide Specifications

Presented by:
Robert Otto Rasmussen, PhD, INCE, PE (TX)
Paul D. Wiegand, PE (IA)
Dale S. Harrington, PE (IA)

Concrete Pavement Surface Characteristics

GUIDE SPECIFICATIONS

Monitor Texturing Operations

A Vision of a Specification

...Midwest Concrete Consortium (MC²), Sep 2004...

- The tire-pavement noise shall not exceed $X$ dBA when measured by $Z$ procedure at $D$ days after opening to traffic.

Warranty?
- This noise threshold shall not be exceeded after $T$ years.

States are looking for this NOW!
Guidance is needed to fill in the missing details!

Guide 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
Methods Specifications

- Diamond Grinding
- Artificial Turf Drag
- Longitudinal Tining
- Transverse Tining

Methods: Diamond Grinding

- “Texturing Concrete Pavement for Reduced Tire/Pavement Noise using Diamond Grinding” (CPSCP GS1)
- Developed in cooperation with International Grooving and Grinding Association (IGGA)

Methods: Turf Drag

- “Texturing Concrete Pavement for Reduced Tire/Pavement Noise using Artificial Turf Drag” (CPSCP GS2)
- Developed from both US and German Practice (FGSV M OB)

Say it with me...

Forschungsgesellschaft für Straßen- und Verkehrswesen
Merkblatt für die Herstellung von Oberflächen-Texturen auf Verkehrsflächen aus Beton

Methods: Turf Drag

- Construction
  - 5’ of turf in contact with concrete
  - Curled or fibrillated PE
  - 5/8 to 1-1/4” blades at 60 oz/sy
  - Keep it clean!
- Texture Requirements
  - Minimum average MTD/ETD of 0.03 in.
  - Corrections by grinding and/or grooving
- Curing
  - Double app (180 sy/gal each)
  - Single app OK under ideal conditions
  - 1st coat: <10 mins, 2nd coat: <30 mins

Methods: Longitudinal Tining

- “Texturing Concrete Pavement for Reduced Tire/Pavement Noise using Longitudinal Tining” (CPSCP GS3)
- “Texturing... using Transverse Tining” (CPSCP GS4)

Methods: Transverse Tining

- “Texturing Concrete Pavement for Reduced Tire/Pavement Noise using Transverse Tining” (CPSCP GS4)
**Methods: Tining**
- Drag Pretexture
  - Turf similar to turf drag spec
  - Burlap ≥ 10 oz/sq yd and frayed 2 to 6"
- Tining
  - 3/4” spacing longitudinal
  - 1/2” spacing transverse
  - 1/8” depth
  - Automated control
- Uniformity is critical
- Curing
  - Double app (180 sq yd/gal each)
  - Single app OK under ideal conditions
  - 1st coat: <10 mins, 2nd coat: <30 mins

**End-Result Specification**
- QC testing using texture (to predict noise)
- Acceptance testing by contractor using OBSI (for pay factors / corrective action)
- Verification testing option for owner-agency
- Independent assurance testing if > 3 dBA between contractor and owner-agency
- 528-ft test segments
- Disregard structures, etc.
- Scaled pay adjustments
- Correct by grinding

**End-Result Specification**
- "Recommended Practice for Accepting New Concrete Pavement Surfaces for Tire/Pavement Noise" (CPSCP PP 1)

**End-Result Specification**
- Quality Assurance (QA) approach
- End-result spec with OBSI overall sound intensity level as quality characteristic
- Prescriptive texture specs should first be minimized or eliminated
- Staged implementation is critical
  (recommendations provided in appendix)

**Concrete Pavement Surface Characteristics**

Session 8: How to Select the Right Texture

Presented by:
Robert Otto Rasmussen, PhD, INCE, PE (TX)
Paul D. Wiegand, PE (IA)
Dale S. Harrington, PE (IA)
Selecting the Right Texture

- Considerations
  - Variability is large, and it is everywhere!
  - Today, we choose textures for:
    - Function (especially Friction)
    - Economy
    - Durability
  - Rarely, if ever, do we optimize the texture for overall functional performance
    - What do we need to learn to do this?
  - We also cannot optimize for noise alone, as this might conflict with other properties we care about

Functional Durability

- Friction versus Noise
- Age and wear influence:
  - Texture changes
    - Mortar wears away
    - Aggregates polish
  - Cracking, rutting, faulting, spalling
    - Distress
    - Repairs
  - Winter maintenance
    - Chemicals added to pavement (deicers, etc.)
    - Plow damage

Selecting the Right Texture

- Functional Demands
- Match to the Functional Supply from a given texture
- Friction, Noise, and Smoothness
Session 9: Ongoing Activities

Concrete Pavement Surface Characteristics

Presented by:
- Robert Otto Rasmussen, PhD, INCE, PE (TX)
- Paul D. Wiegand, PE (IA)
- Dale S. Harrington, PE (IA)

International Activities – EU Directives
- 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

International Activities – Case Study: NL
- Innovative pavement solutions
  - “Roads to the Future”
    - Public-private research and demonstrations
    - Facilitation of next generation of pavement solutions to address noise and other societal requirements

Domestic Activities – FHWA
- Profile Viewing and Analysis (ProVAL)
  - Software support
  - Workshops
- Friction equipment evaluation
- Equipment loan program
- Tire-Pavement Noise 101 workshops
- Little Book of Quieter Pavements
- Technical Working Groups (TWG)
  - Tire-pavement noise
  - Smoothness

Domestic Activities – CP Tech Center
- National Concrete Pavement Technology Center at Iowa State University
  - CP Road Map: Long-Term Plan for Concrete Pavement Research and Technology
  - Two-Lift Concrete Paving Demonstration Projects (Kansas, Missouri)

Domestic Activities – Industry
- ACPA / IGGA
  - Next Generation Concrete Surface (NGCS)
  - Flush diamond grinding and grooving
Domestic Activities – State Research

- State DOT
  - Quieter Concrete Pavement Research
  - CA, CO, KS, MN, TX, WA, etc.
- Pooled Fund
  - TPF-5(135) – Tire/Pavement Noise Research Consortium
- 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