Relating Texture to Tire-Pavement Noise

21st Annual Road Profilers Users' Group
Atlanta, Georgia
10 December 2009

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National Concrete Pavement Technology Center

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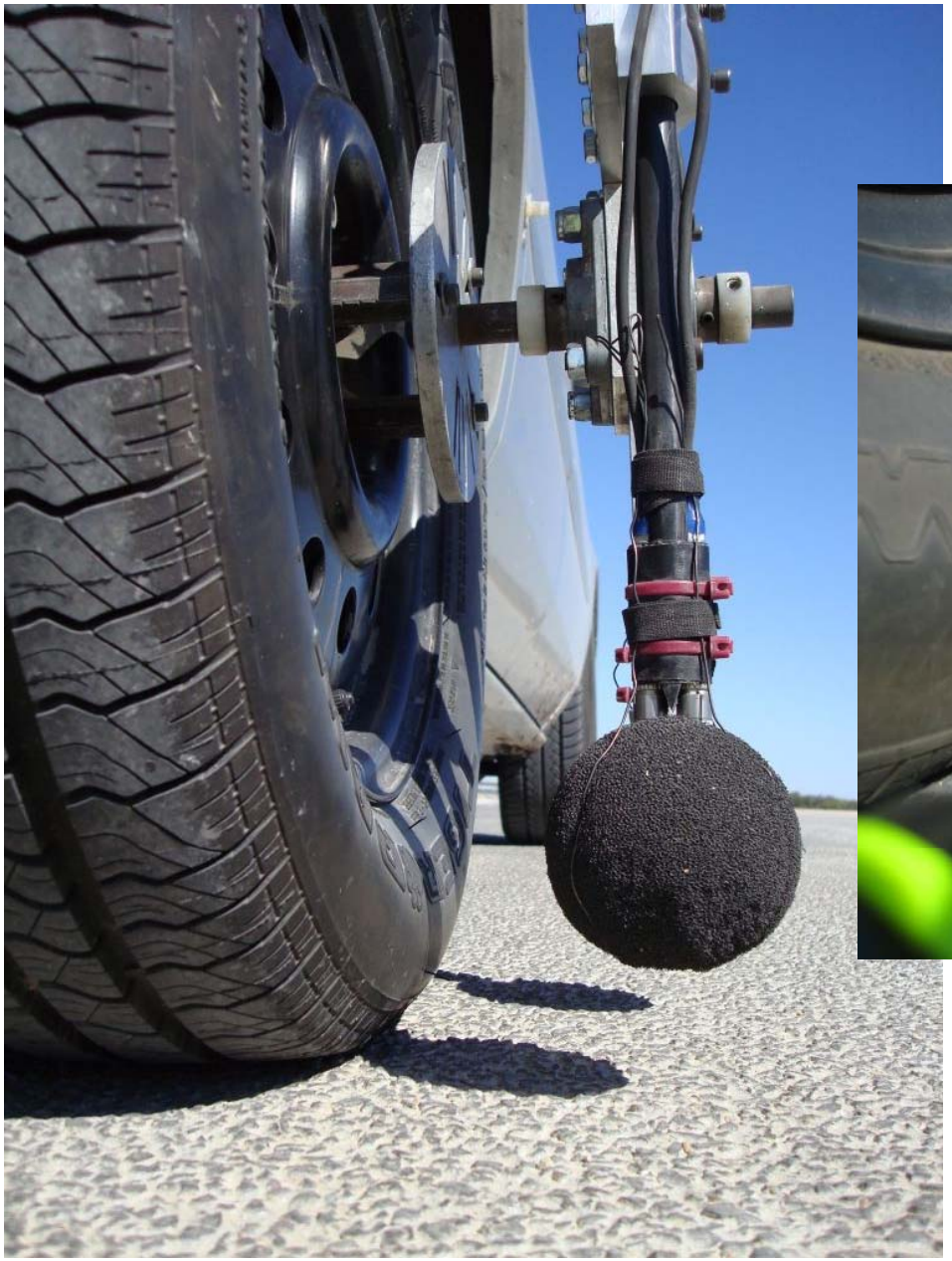
The Transtec Group, Inc.

Tire-Pavement Noise Measurement is a Response Type Measurement

On-Board Sound Intensity



AASHTO TP 76

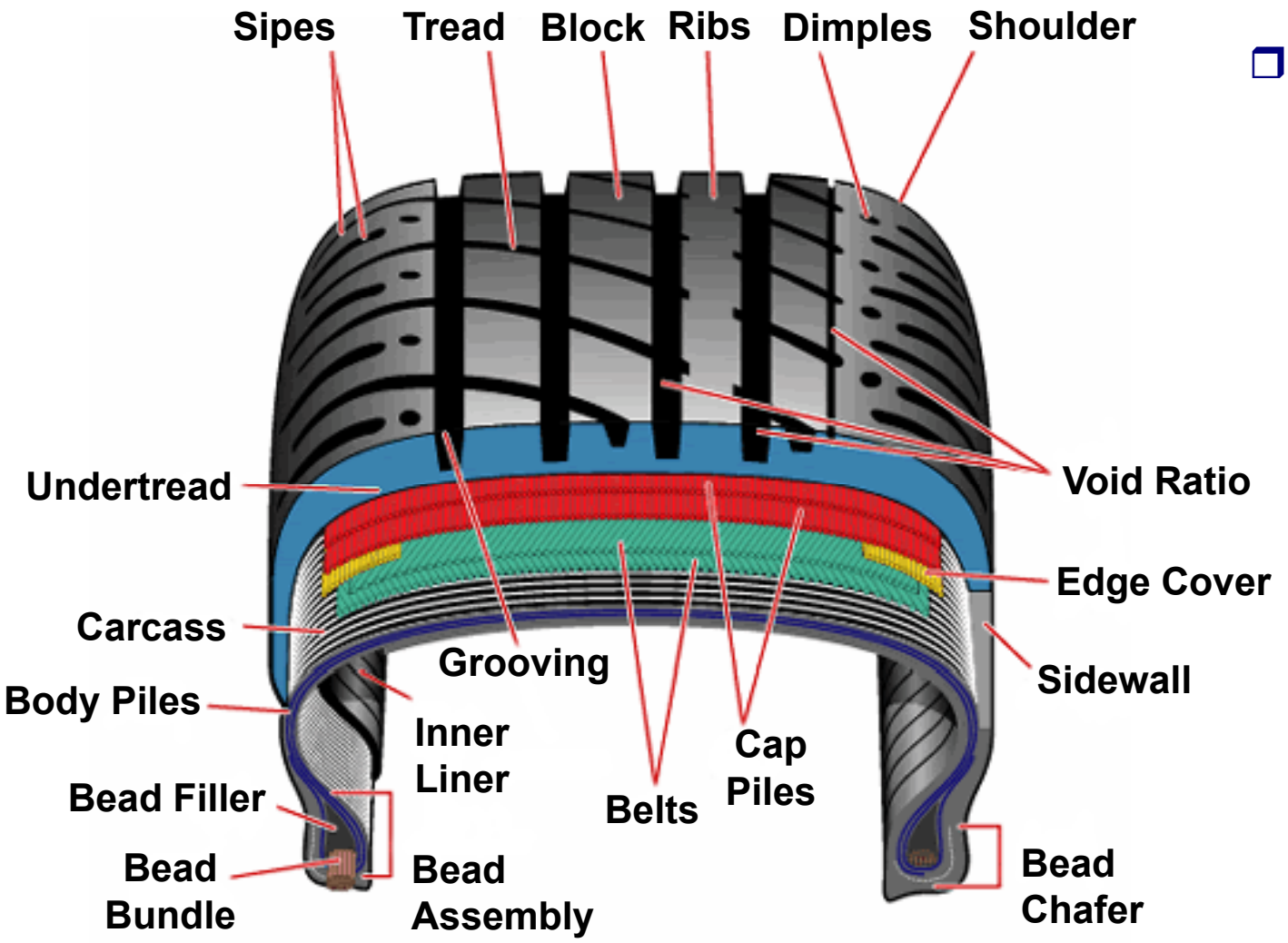
On-Board Sound Intensity

ASTM F 2493 Standard Reference Test Tire (SRTT)

Goodyear Aquatred III

Source: Paul Donavan

Tire Basics – Tire Construction

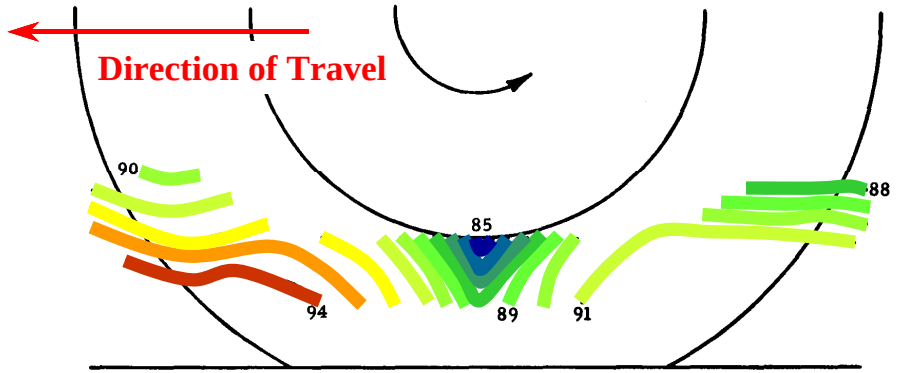


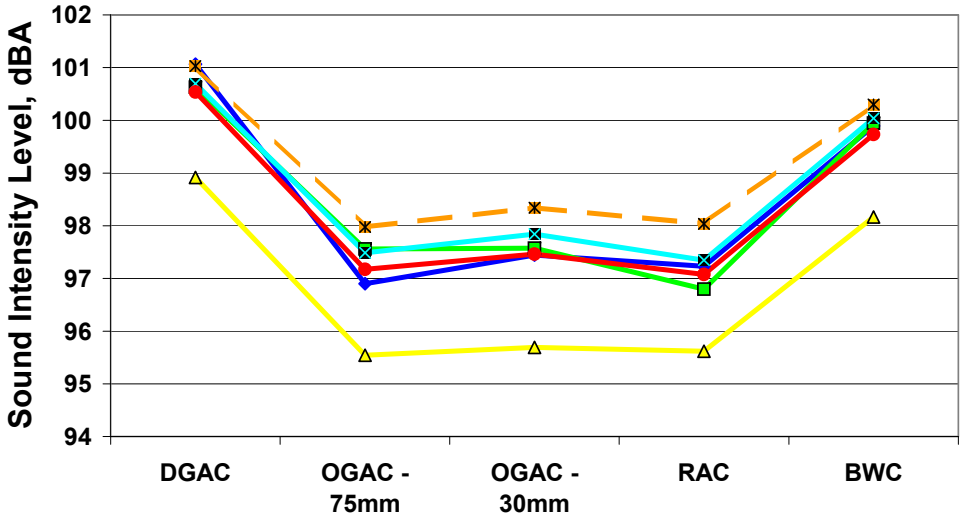
- Tradeoffs:
  - Wet handling
  - Wet traction
  - Hydroplaning
  - Rolling resistance
  - Tread wear
  - Dry handling
  - Snow
  - Ride comfort
  - Pattern noise
  - Road noise
  - "Looks"

Source: Yokohama Tires, Goodyear

Tire Basics - Observations

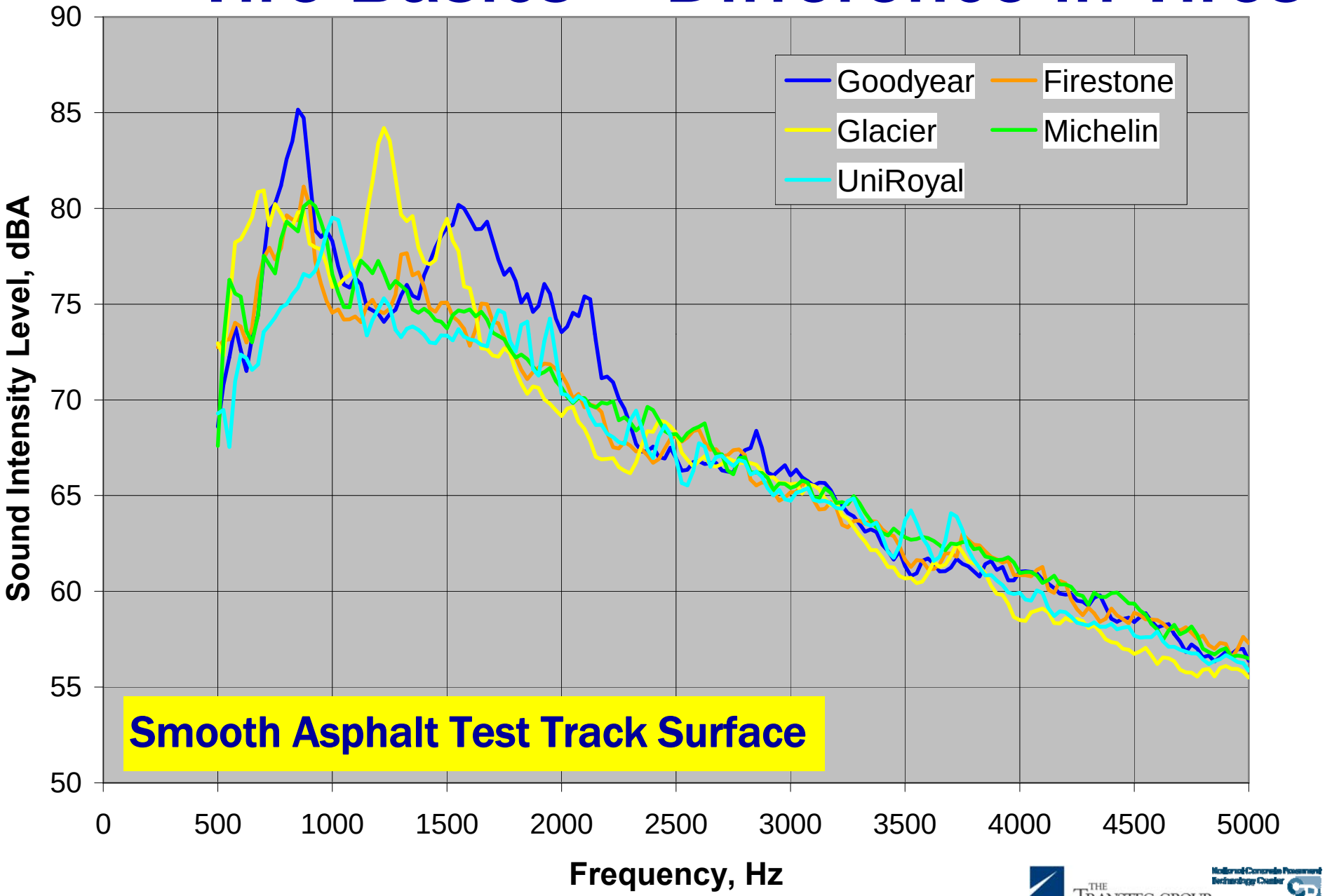
- Tire noise increases with speed at 35 to 40 times *log*(speed)
- Noise sources are low to the ground
- For “normal” tires, overall levels largely independent of tire design





Source: General Motors, Caltrans

Tire Basics – Difference in Tires



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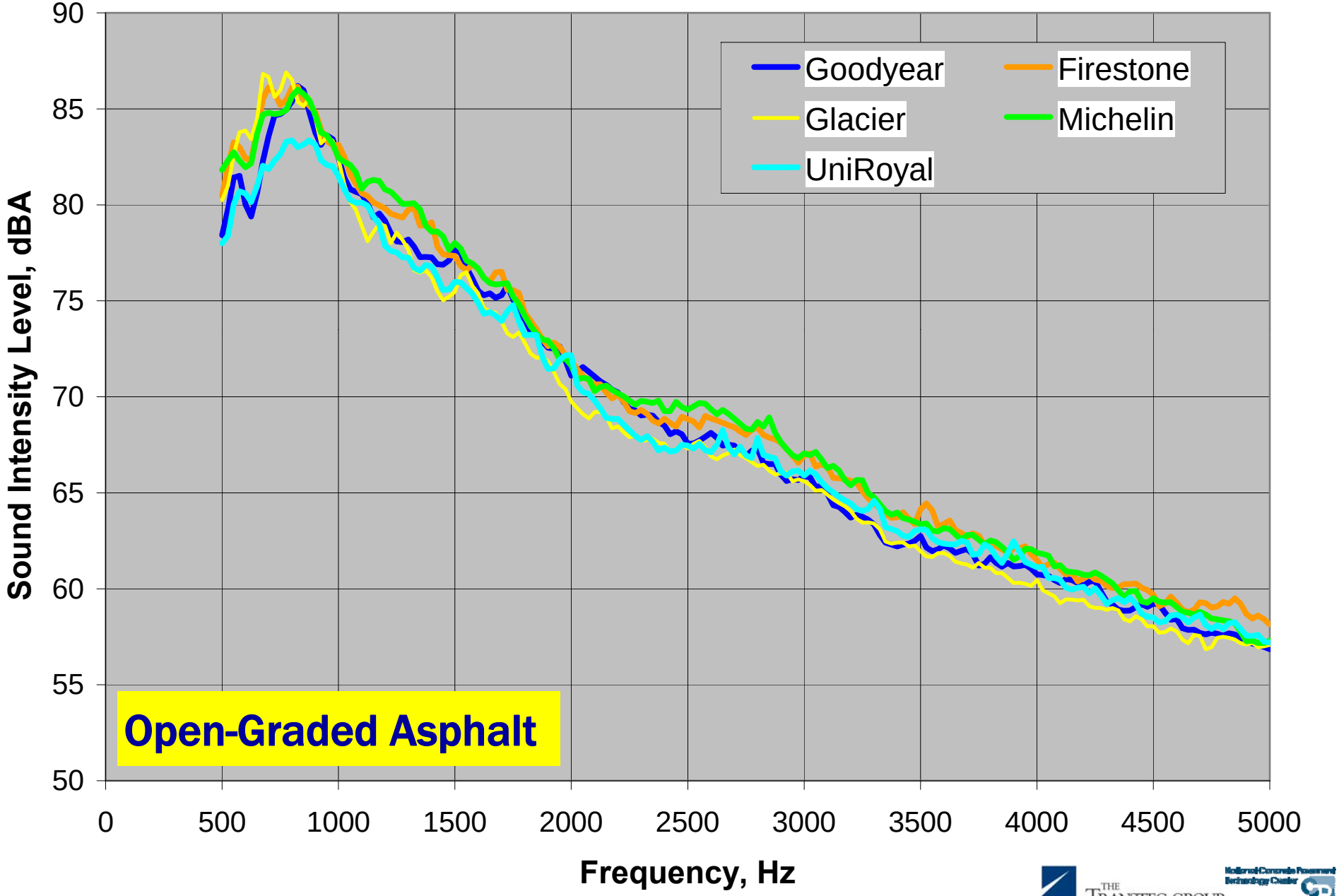

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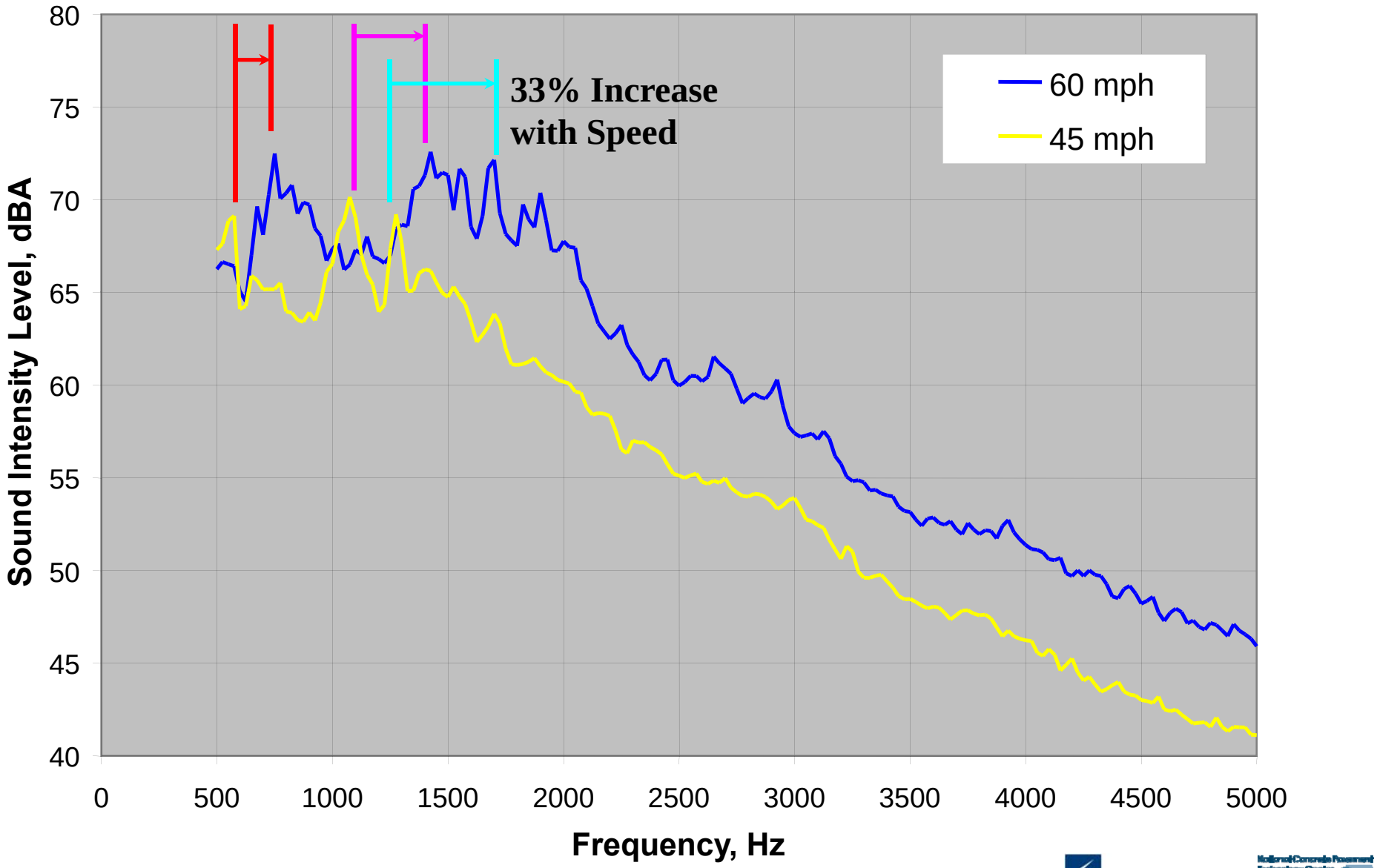
Tire Basics – Tread Pattern



Source: General Motors, Caltrans

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Tire Noise: Pop Quiz

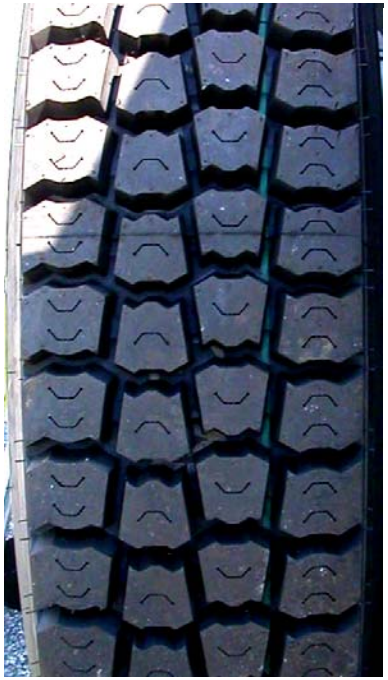
Which is Noisier?

A

B

C

D



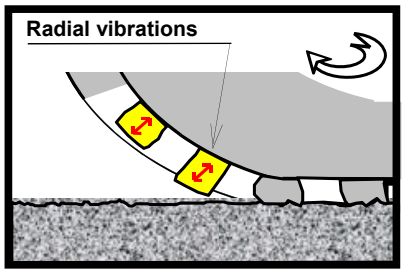
E

Sound Generators

- The ***Hammer***
- The ***Clapper***
- The ***Squeaker***
- The ***Scrubber***
- The ***Suction Cup***

Generation Mechanisms – Hammer

- 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

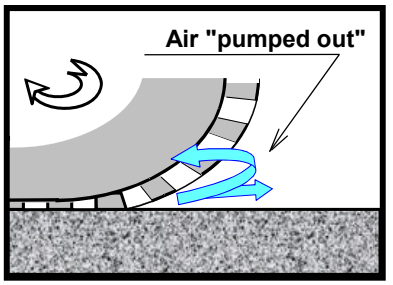


Make impacts soft and random

Source: Purdue SQDH, Ulf Sandberg

Generation Mechanisms – Clapper

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

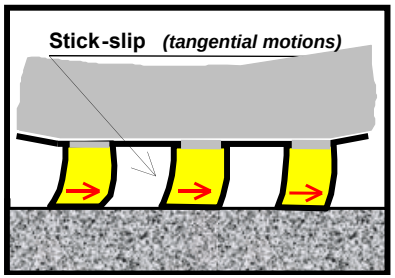


Add pavement porosity and negative texture

Source: Purdue SQDH, Ulf Sandberg

Generation Mechanisms – Squeaker

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

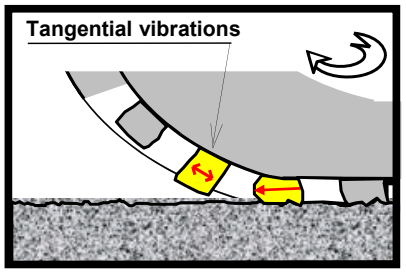


Source: Purdue SQDH, Ulf Sandberg

Increase local friction and increase surface roughness

Generation Mechanisms – Scrubber

- Relative motion of tread blocks and surface prior to "lock-in" & at release
- Causes scrubbing sound
- Mid to high frequency
- Like fingers across rough sand paper

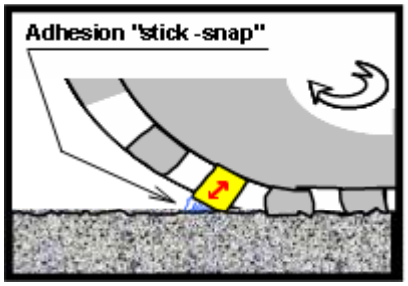


Increase local friction and decrease surface roughness

Source: Purdue SQDH and Ulf Sandberg

Generation Mechanisms – Suction Cup

- Adhesion between tread block and pavement surface causes tread and carcass vibration
- "Stick-snap"
- Depends on adhesive forces between tread and surface



Add microtexture, reduce local adhesion, increase porosity

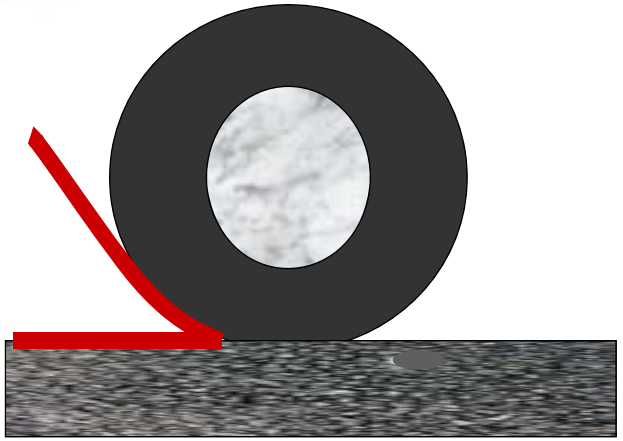
Source: Purdue SQDH, Ulf Sandberg

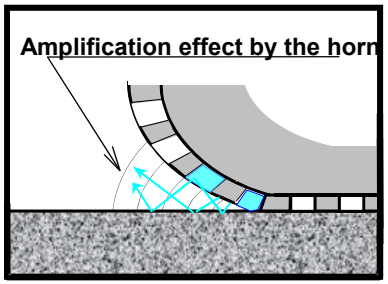
Sound Amplifiers

- The *Horn*
- The *Pop Bottle*
- The *Organ Pipe*
- The *Pie Plate*
- The *Balloon*

Amplification Mechanisms – Horn

- 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

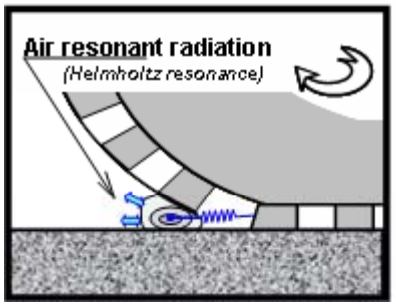




Add pavement porosity

Source: Purdue SQDH, Ulf Sandberg

Amplification Mechanisms – Beer Bottle



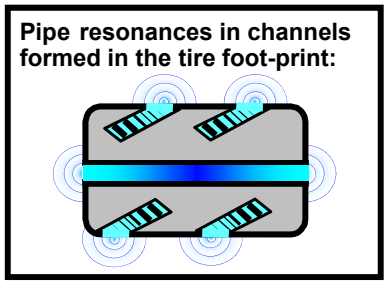
- Source amplification near entrance and exit of contact patch
- Air resonance (Helmholtz) in tread passages as passages open and close
- High frequency effect

Add pavement porosity and negative texture

Source: Purdue SQDH, Ulf Sandberg

Amplification Mechanisms – Organ Pipe

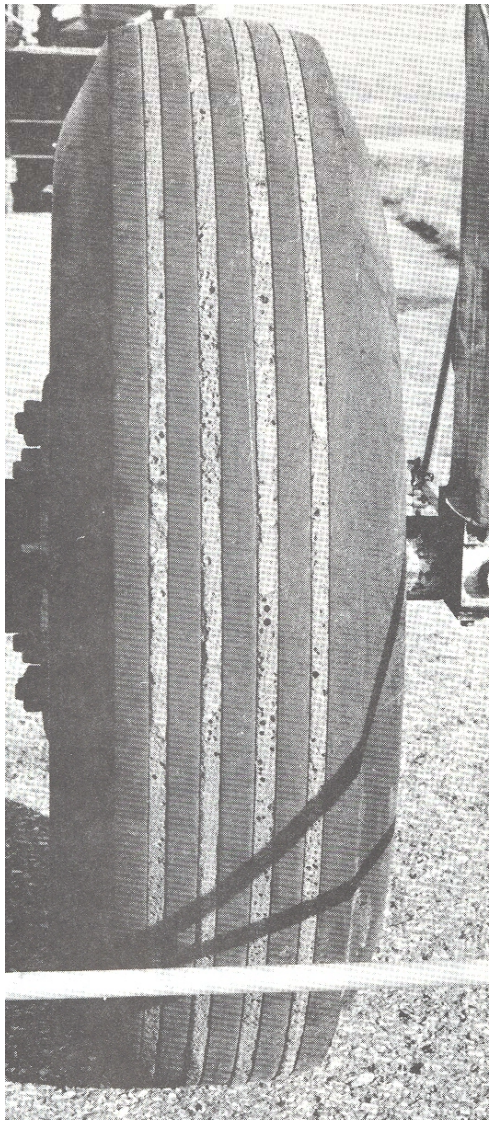
- Channels in tire footprint act like organ pipes, amplifying source
- Radiate sound out from channel
- Mid-frequency effect

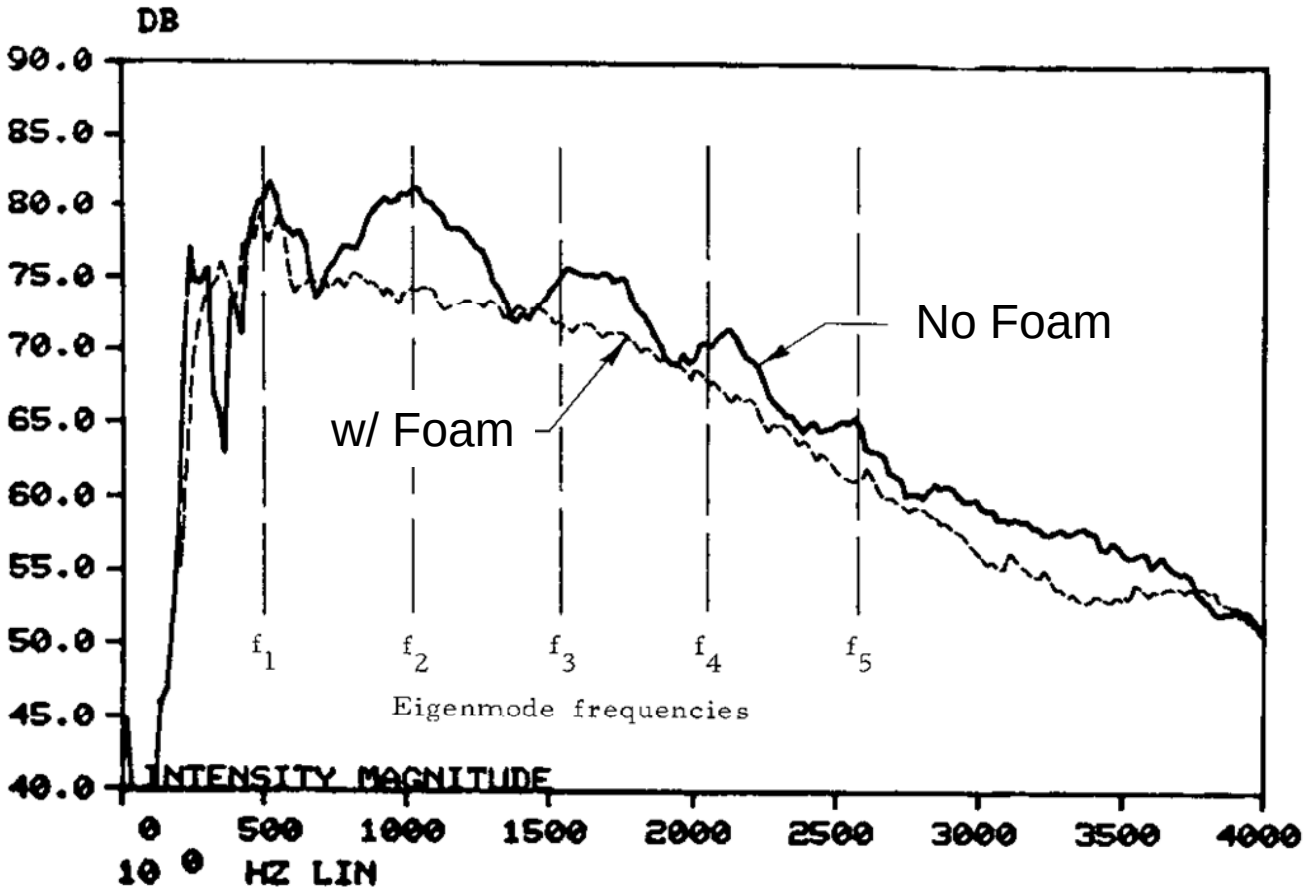


Change void geometries

Source: Purdue SQDH, Ulf Sandberg

Amplification Mechanisms – Organ Pipe





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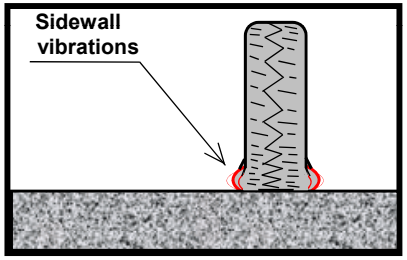
Amplification Mechanisms – Pie Plate

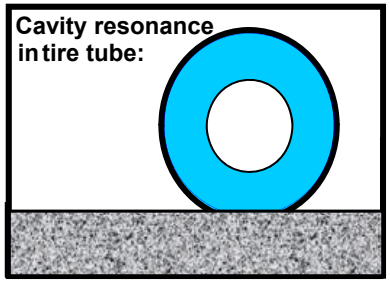
- Vibrations of sidewall amplify noise source
- Radiates sound to the side (sideline radiation)
- Depends on tire construction



Reduce positive texture

Source: Purdue SQDH, Ulf Sandberg

Amplification Mechanisms – Balloon



- Cavity resonance in tire tube
- Like thumping a balloon or kicking a tire
- Lightly damped resonance at low frequency
- Very evident inside vehicle

Reduce 250 Hz “4-inch” excitation

Source: Purdue SQDH, Ulf Sandberg

“The Perfect Storm”

- Texture
  - A 1” characteristic length at 60 mph excites the tire at 1000 Hz
- Tread blocks
  - Dimension of 1” excites the tire at 1000 Hz
- Tire vibration
  - Peaks between 600 and 1000 Hz
- Horn effect
  - Peaks between 800 and 2000 Hz
- Organ pipe
  - Modes between 750 and 1200 Hz
- Human sensitivity
  - Greatest between 1000 and 4000 Hz

Tire Noise: Pop Quiz

Which is Noisier?

Increasing Noise:
9 to 10 dBA
Total Range

A B C D E

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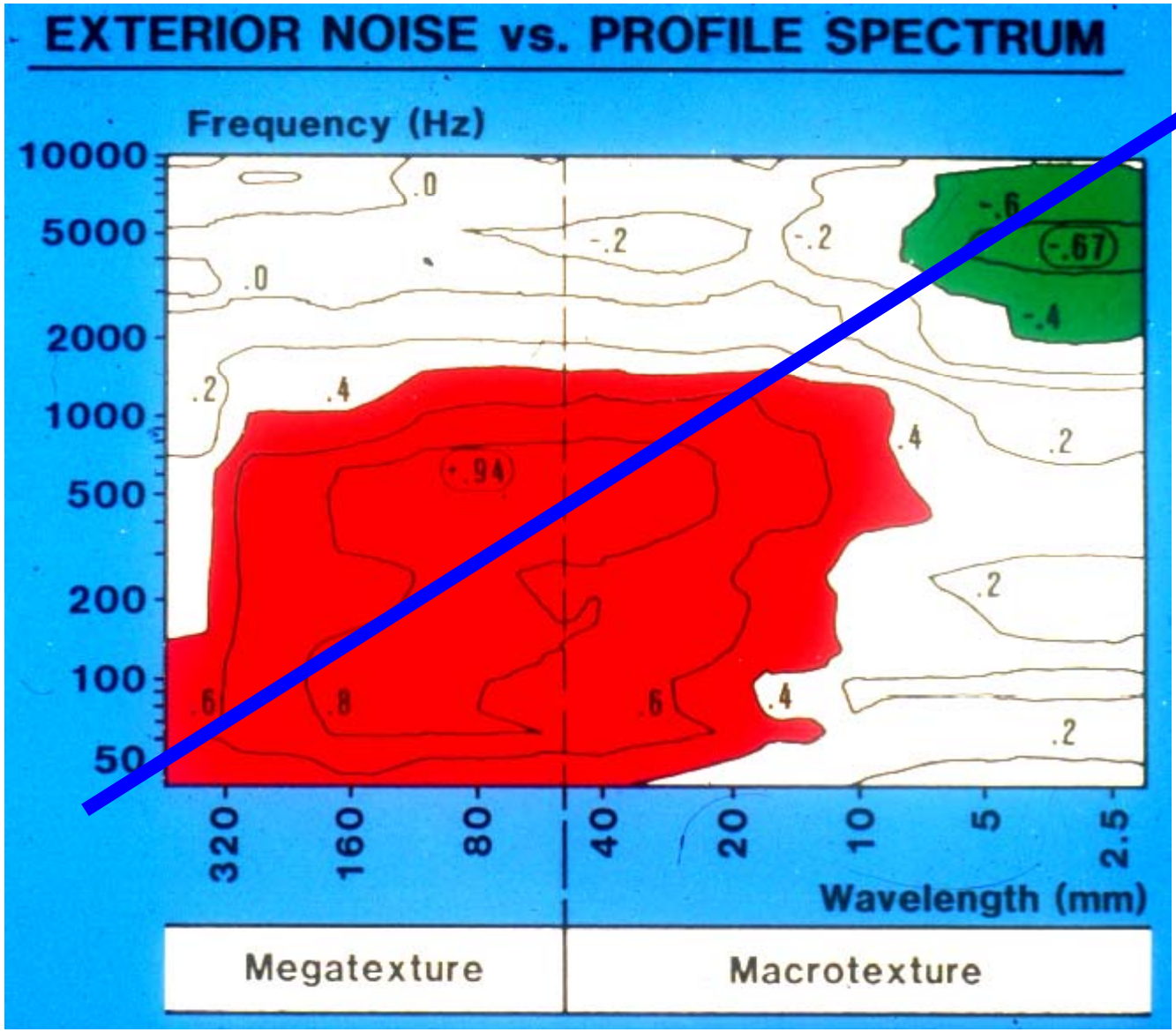
30 years ago



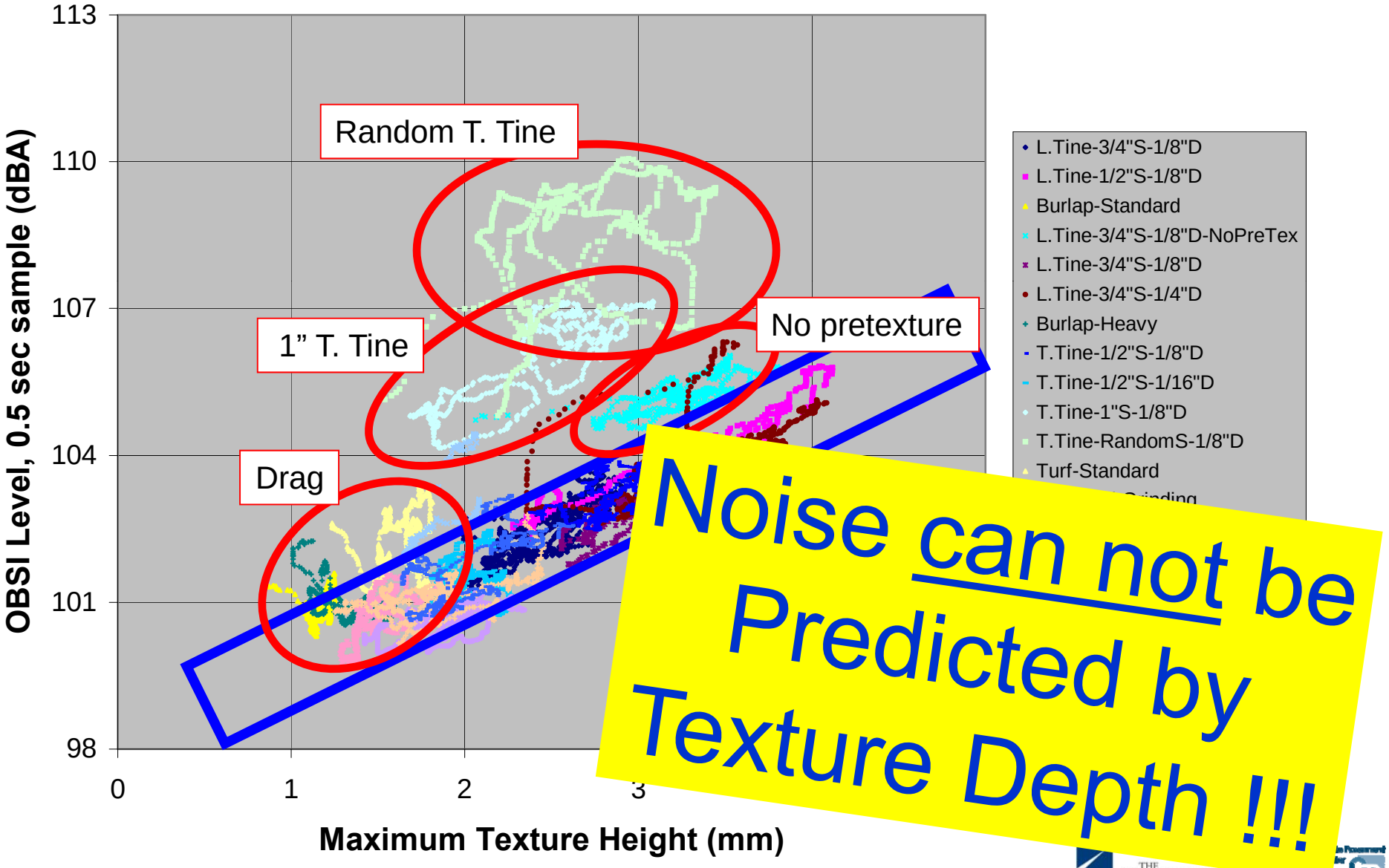
Theory at
80 km/h

Source: Descornet and Sandberg

CP Tech Center Test Sections

- In 3½ years, Over 1000 Unique Textures 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
- 150 miles of test surface in 20 States and 6 Countries

Texture vs. Noise



Noise can not be Predicted by Texture Depth !!!

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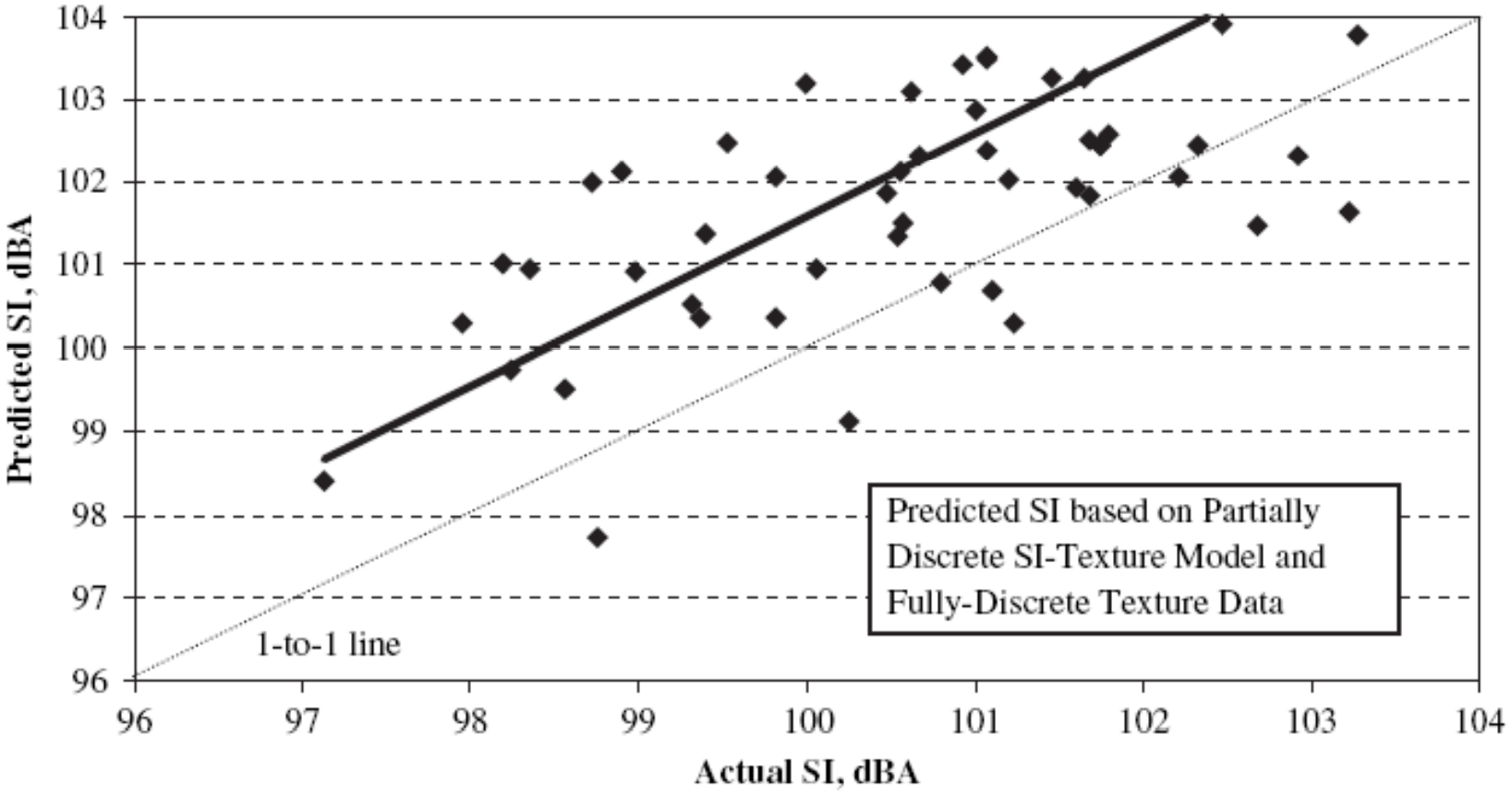
Last month?!?!?



$$SI = 106.63 - 14.28 \times A_1 / A_2 + 2.79 \times RMS - 1.25 \times Dir$$

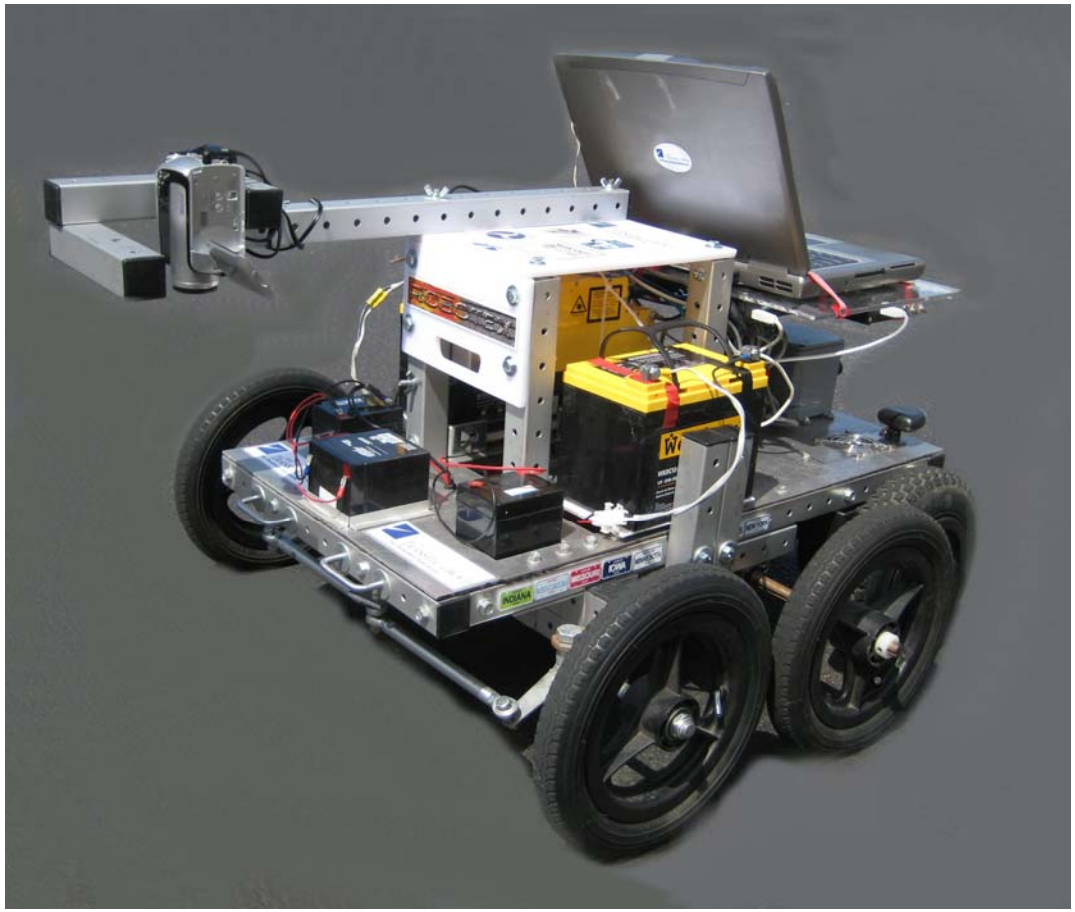
where

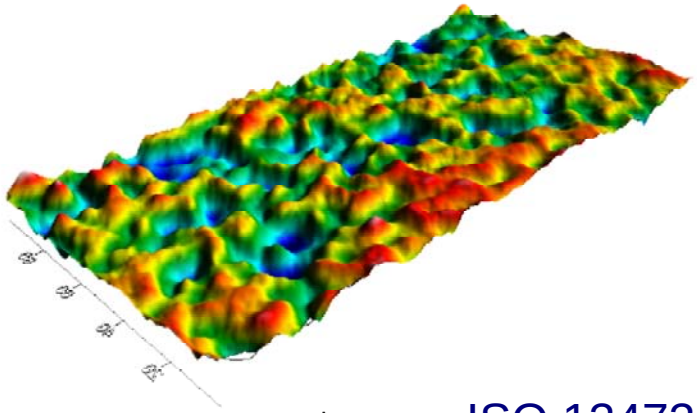
Dir = 0, for transverse or uniform/isotropic texture
= 1 for longitudinal texture.

Source: NCHRP Report 634

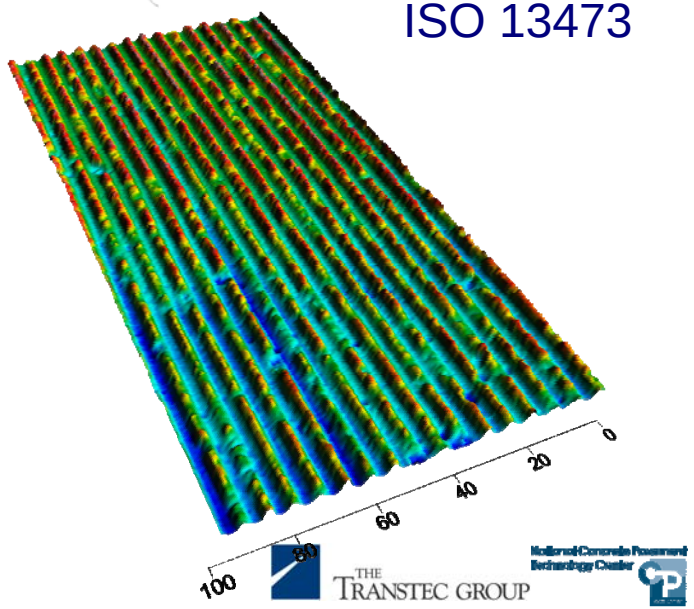
RoboTex 2.0

- Built around LMI-Selcom RoLine Sensor
- Laser height sensor, inertial referencing
- GPS, DMI encoder, video log





ISO 13473



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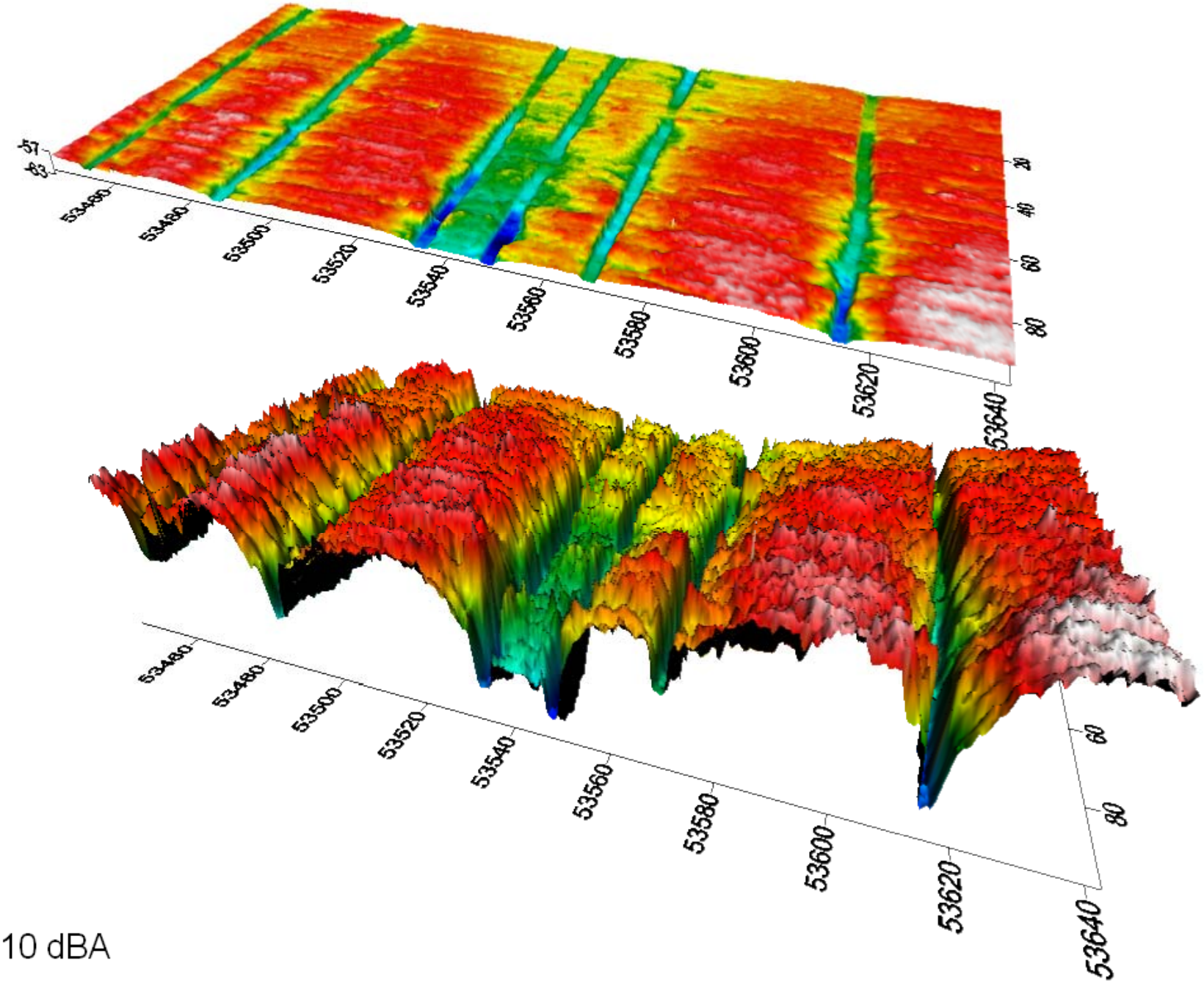
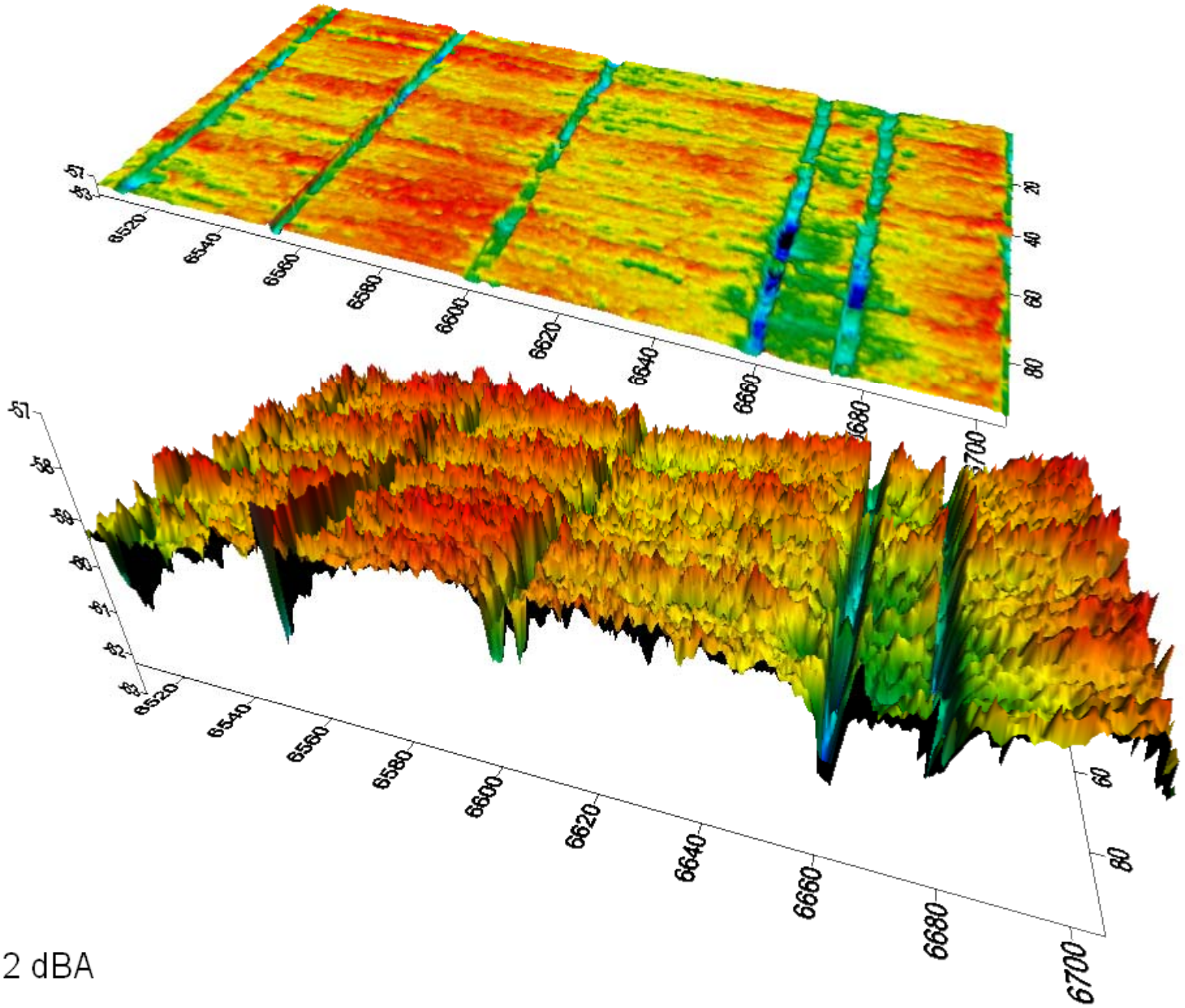
1/8" Deep Transverse Random Spacing + Burlap



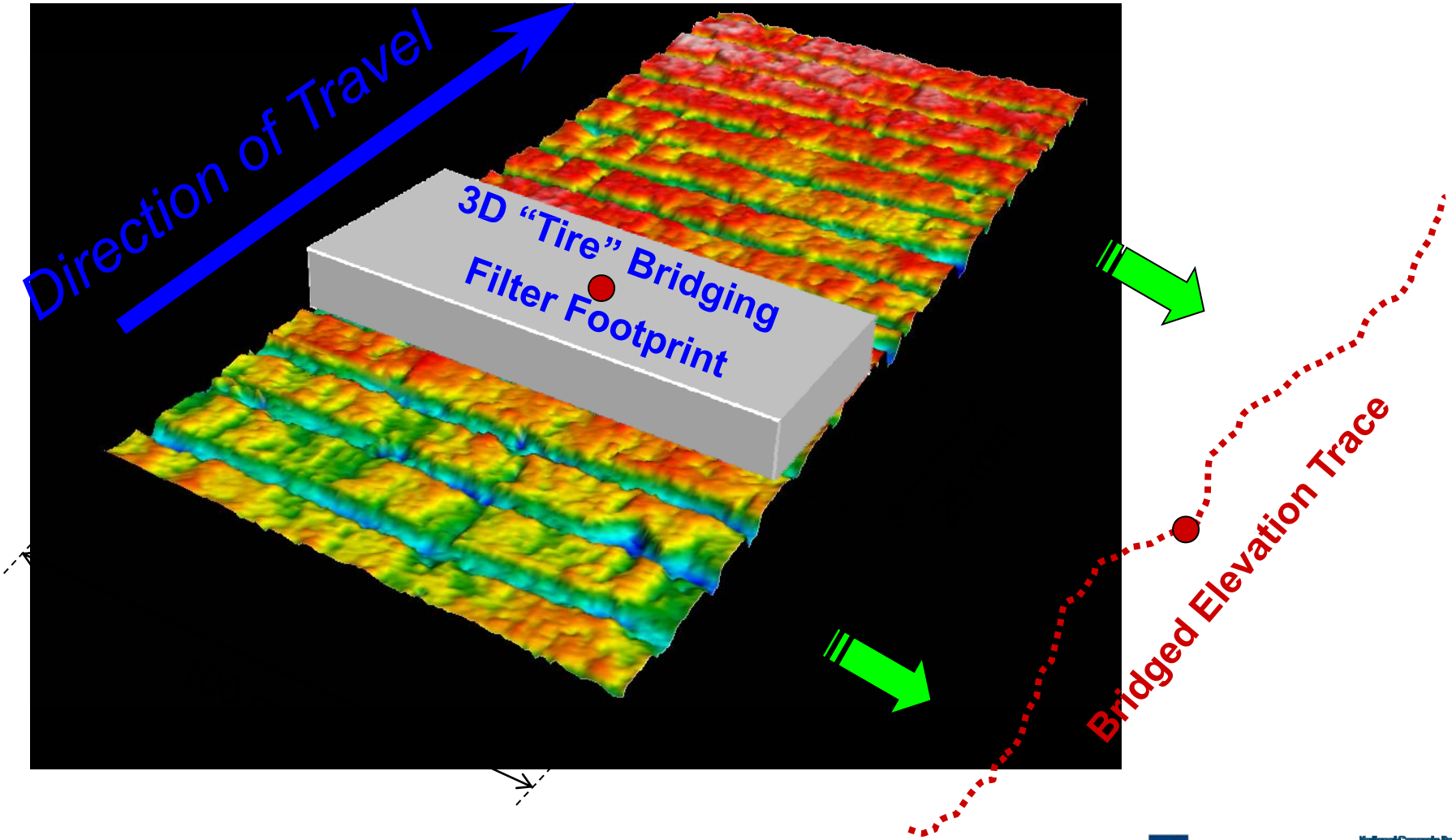
110 dBA

1/8" Deep Transverse Random Spacing + Burlap



102 dBA

Modeling Noise from Texture



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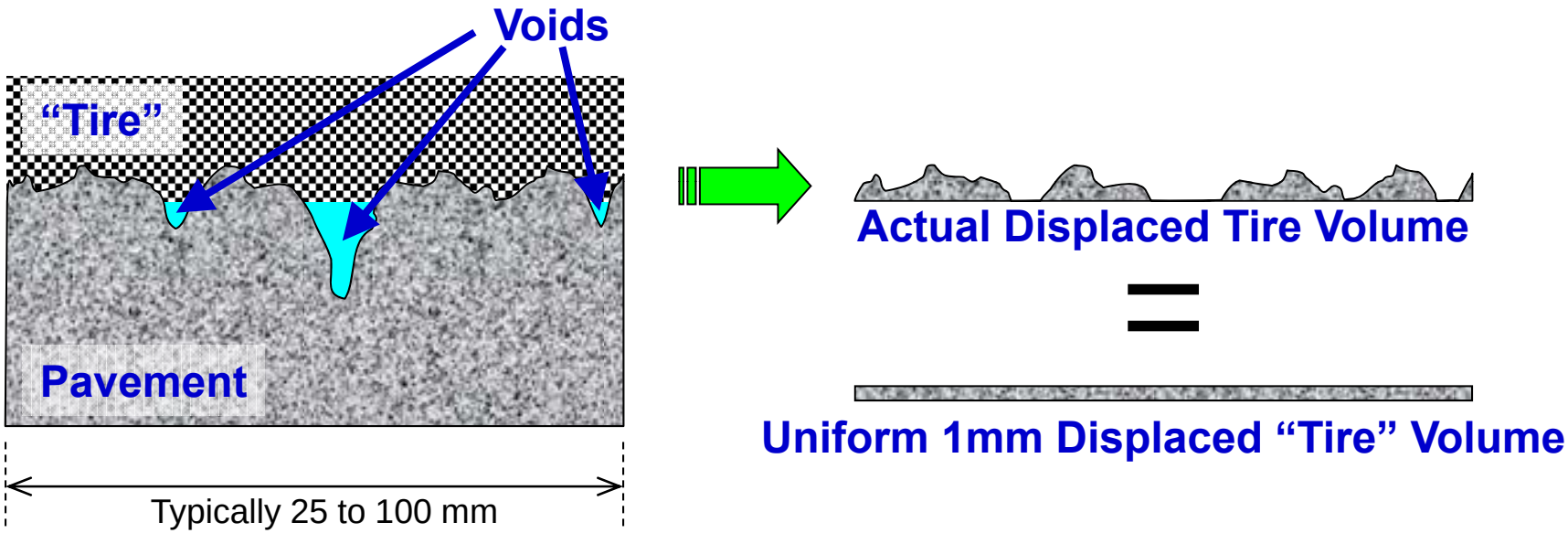

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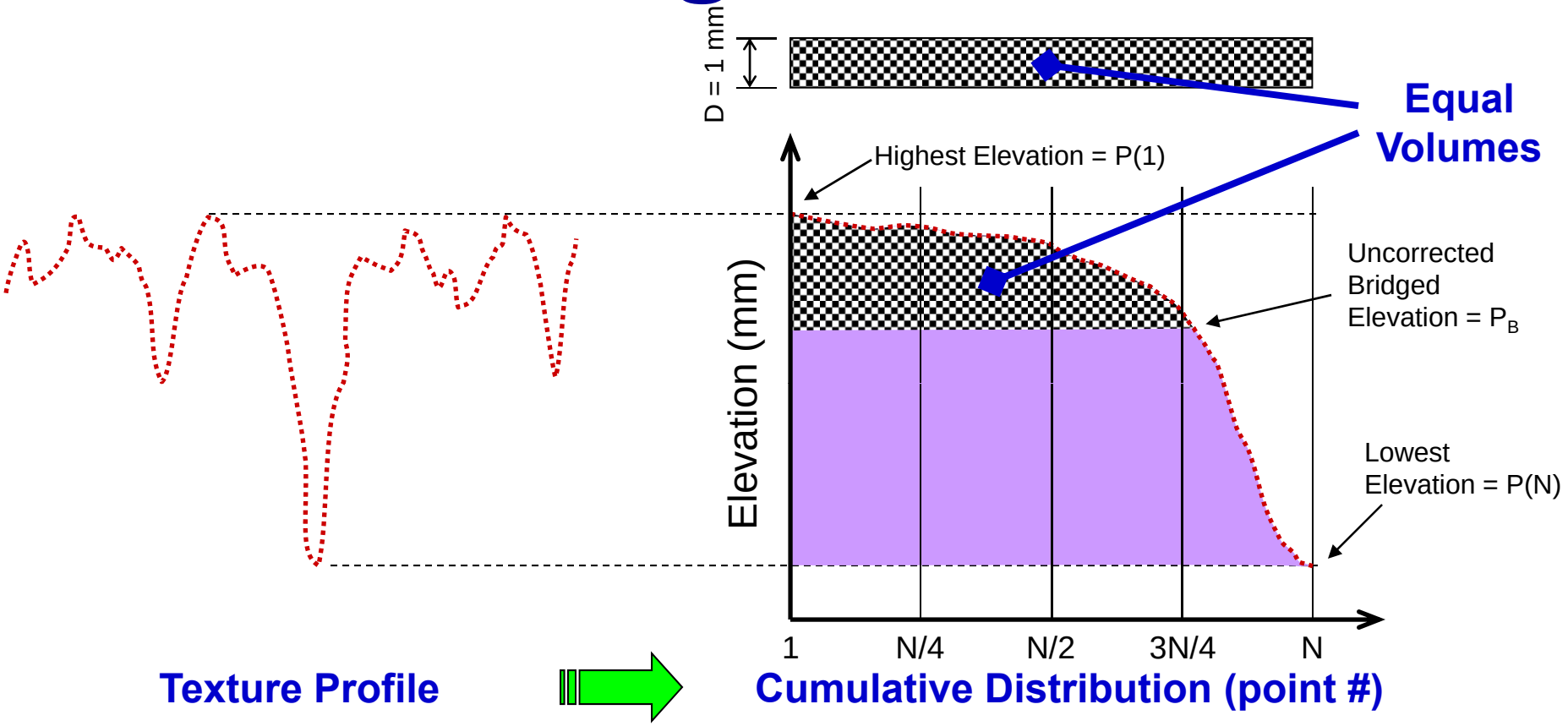

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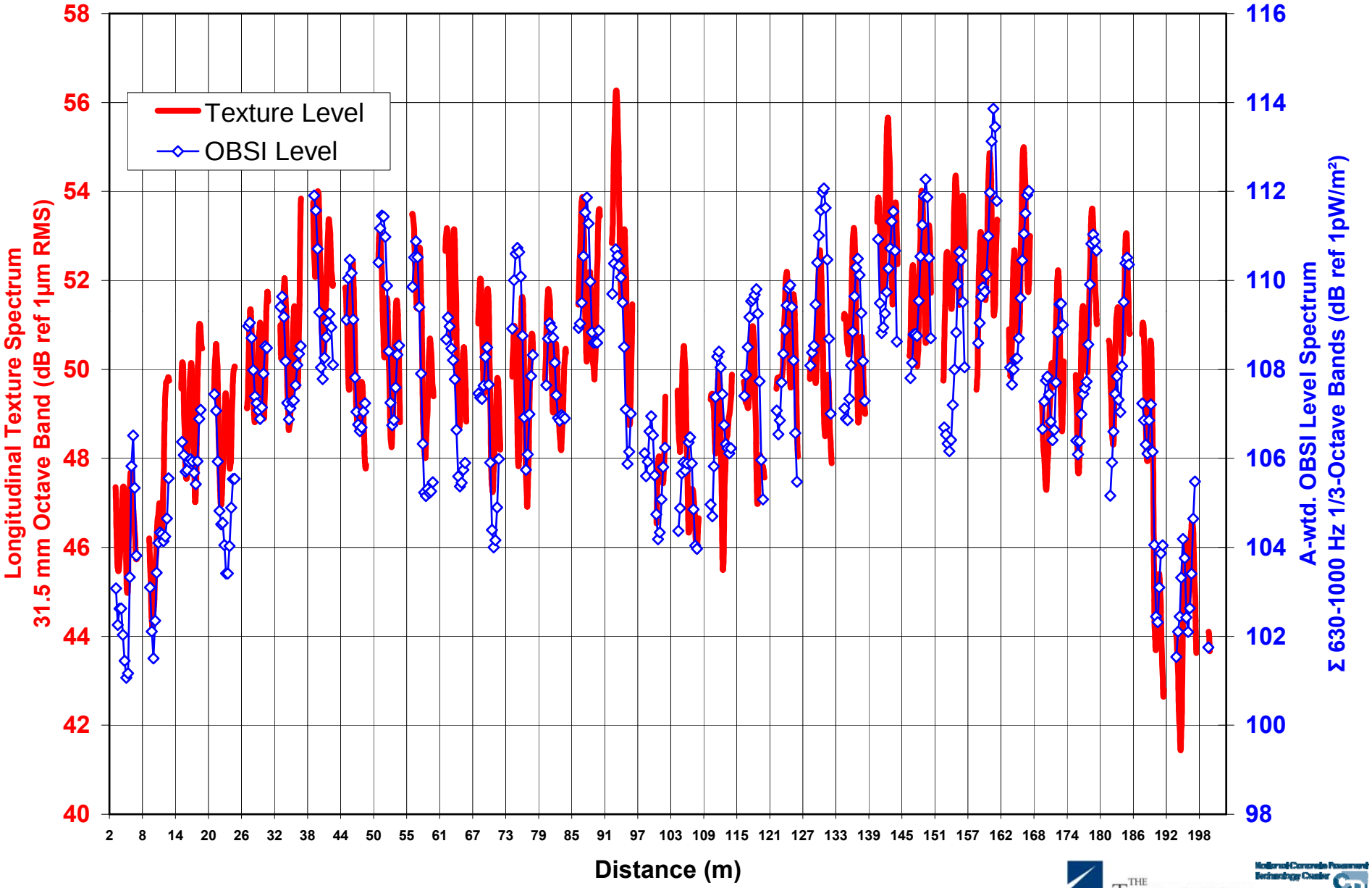

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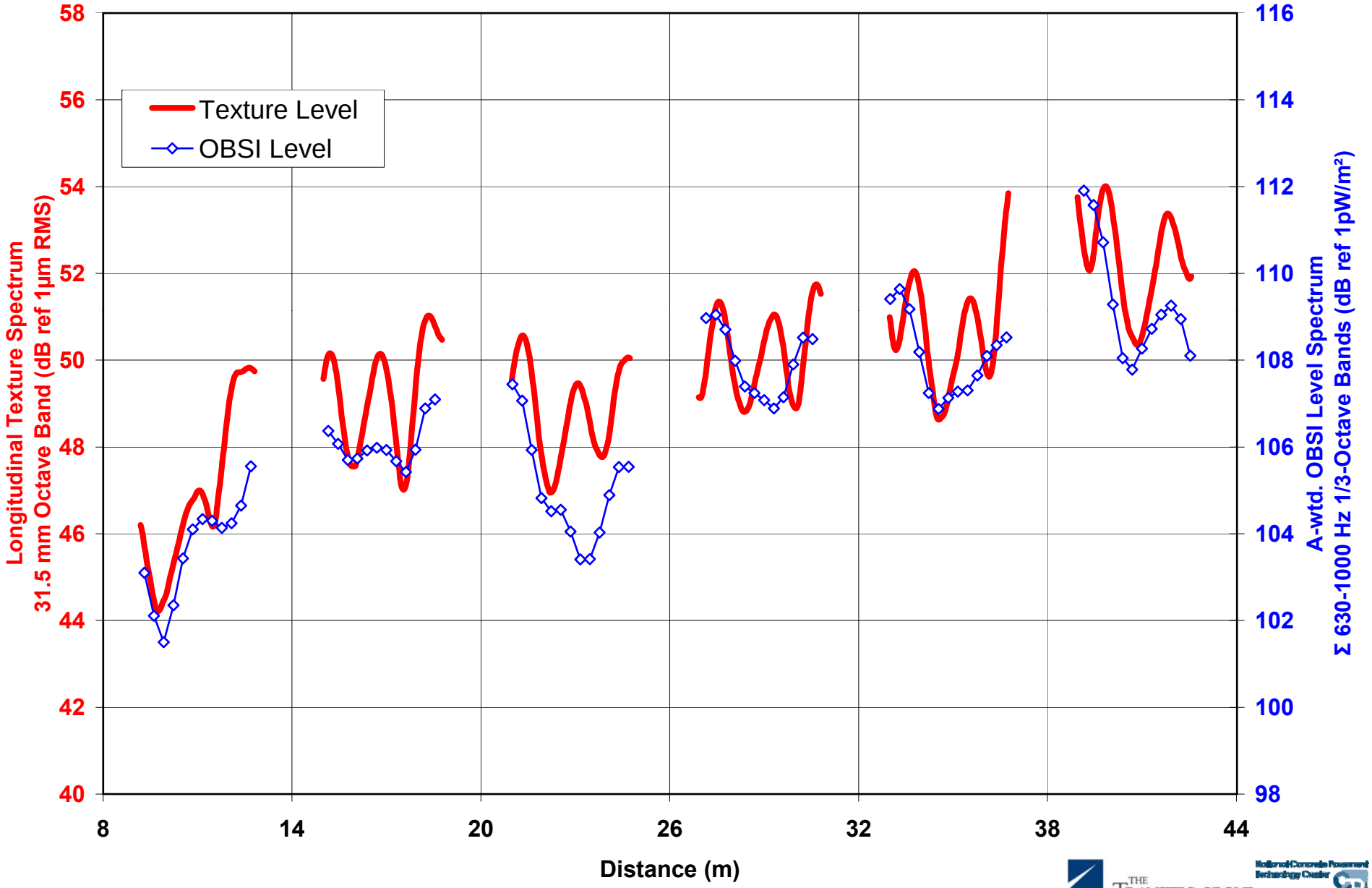
Modeling Noise from Texture



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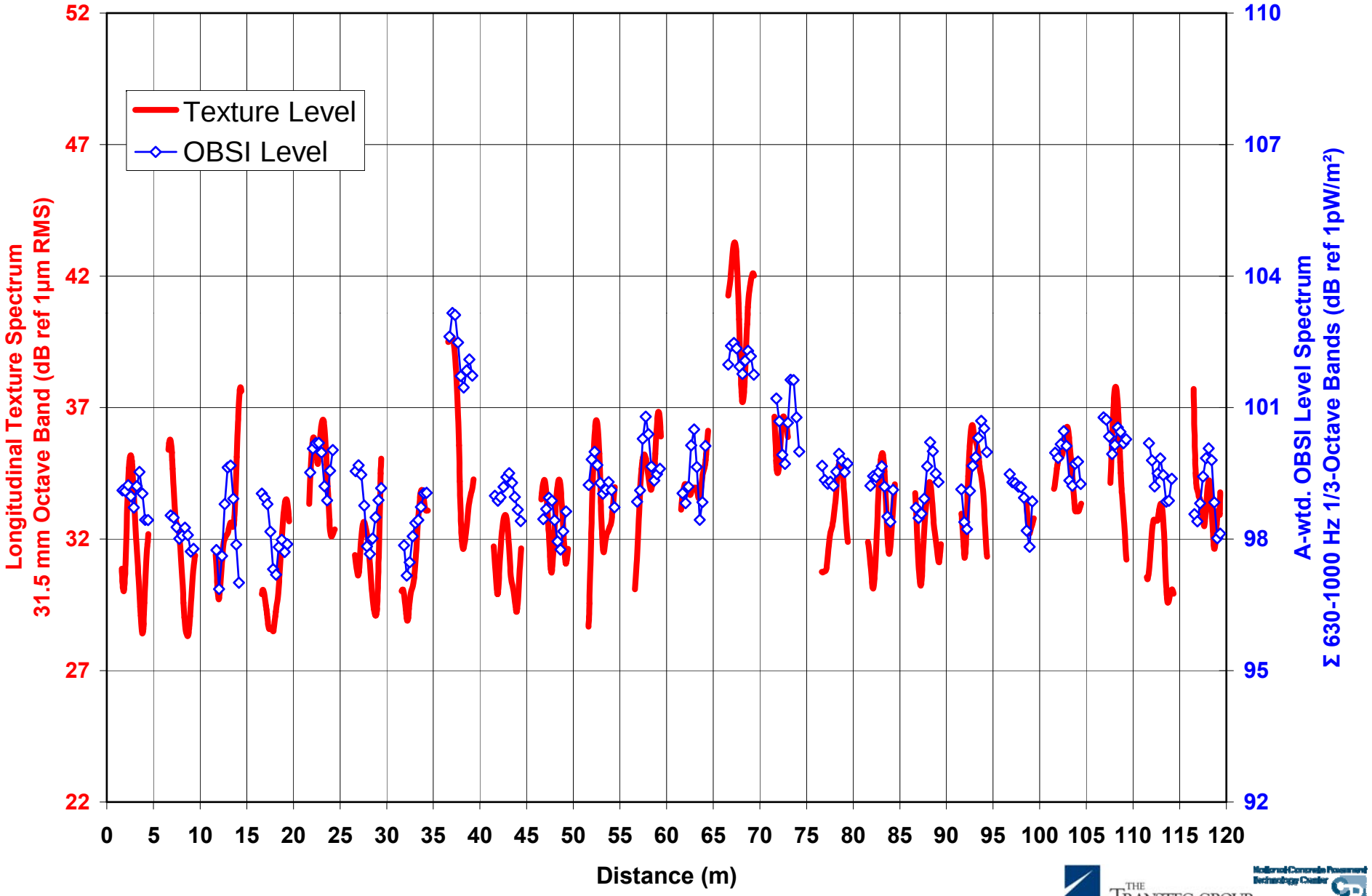

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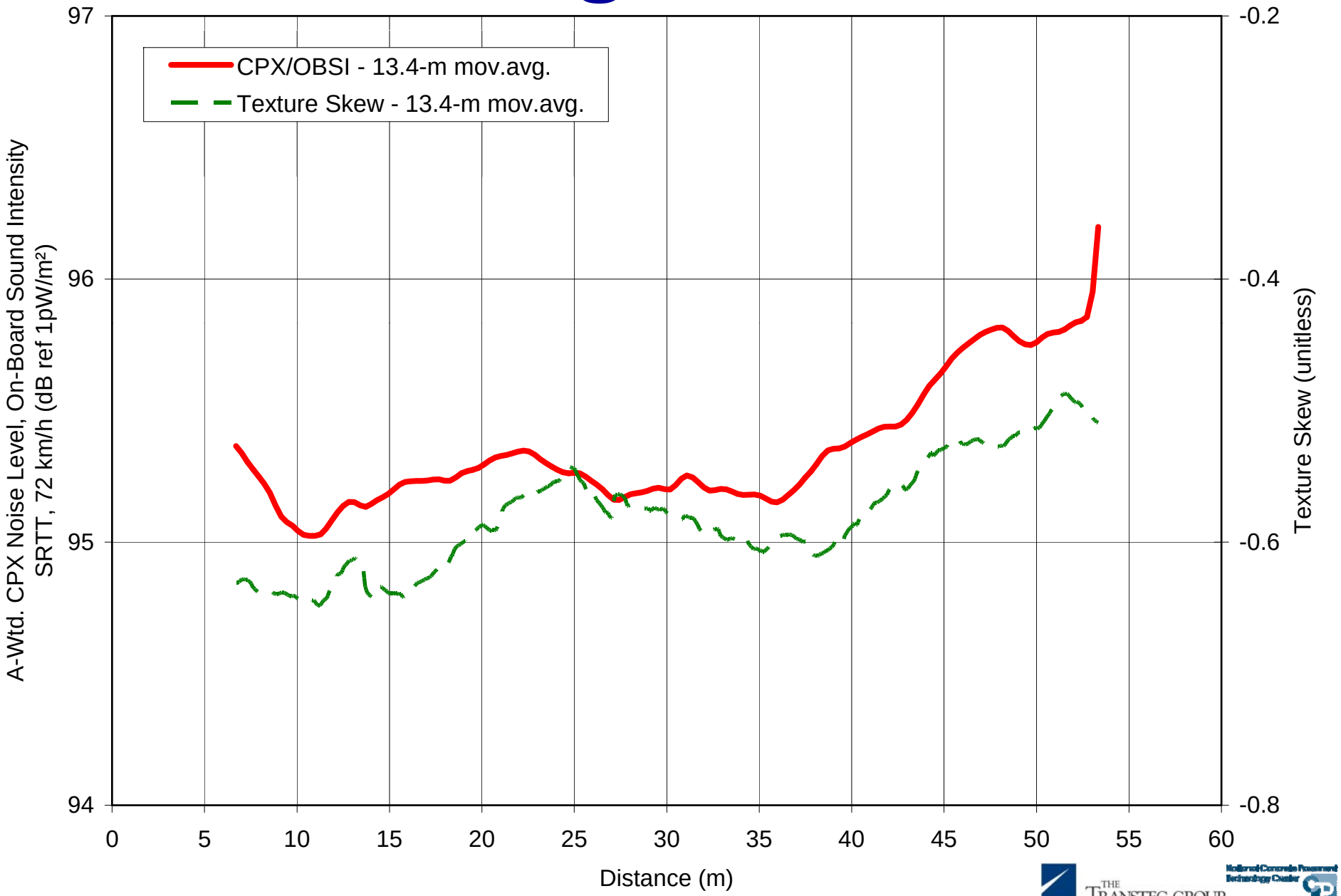

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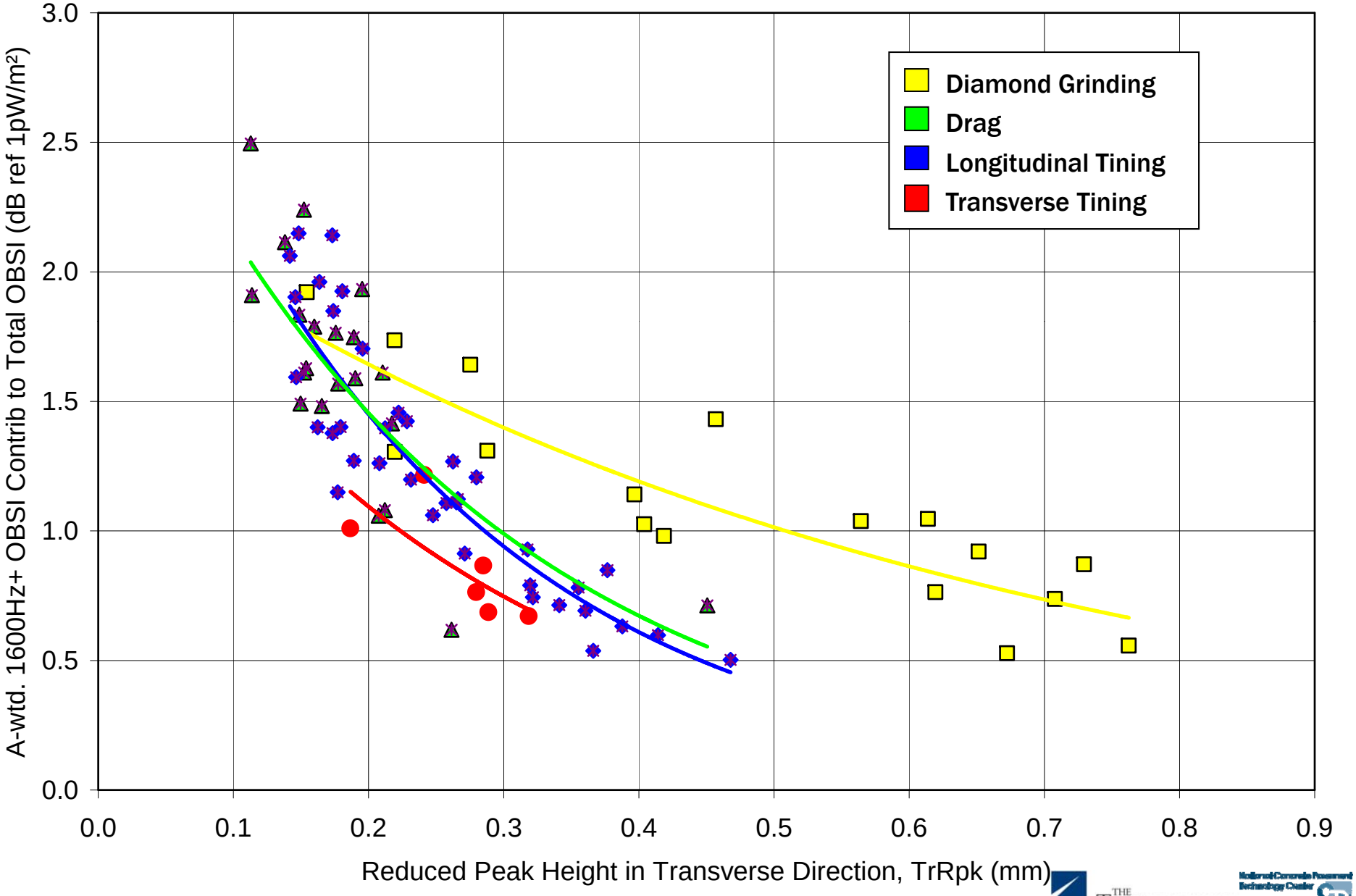

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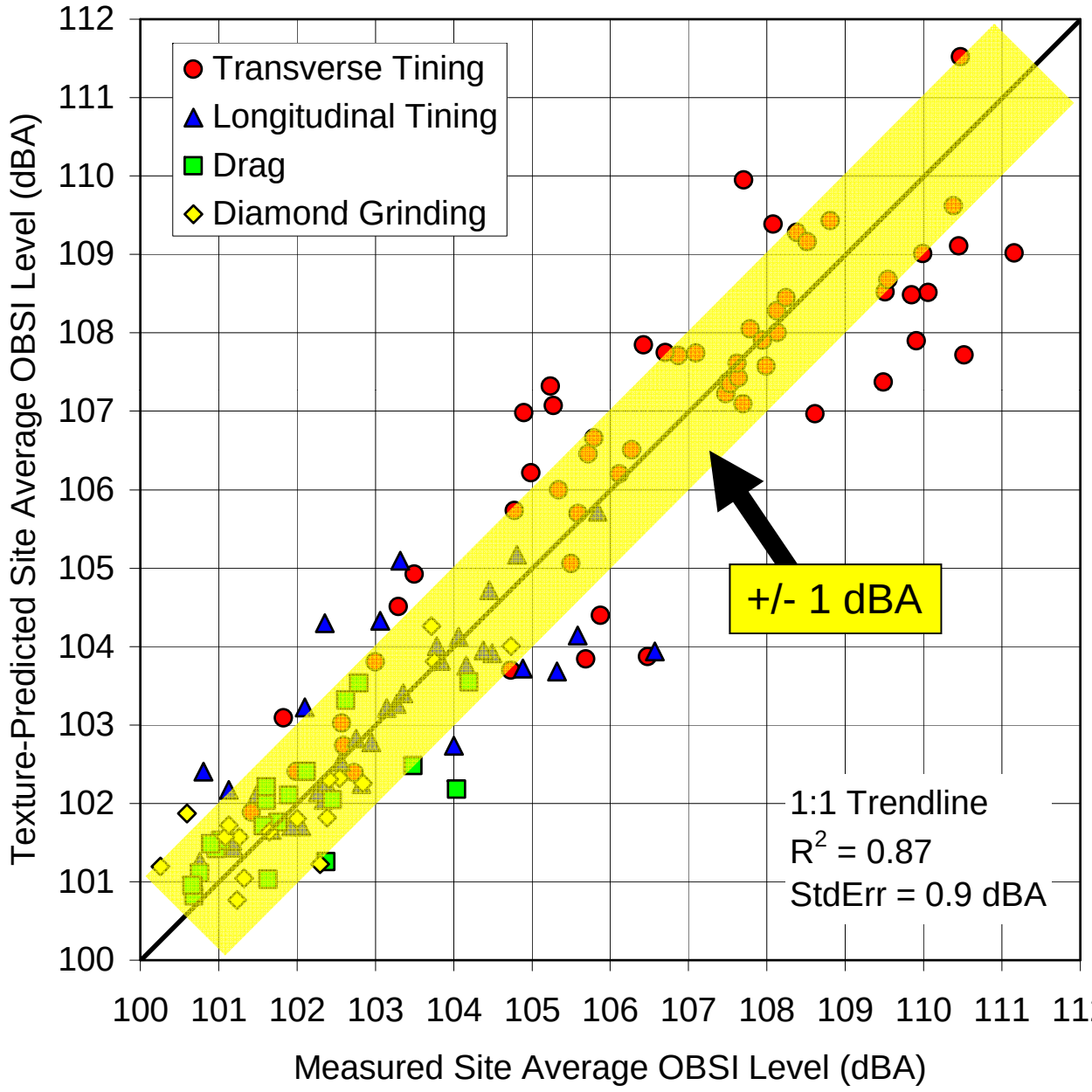

Transverse Tining

OBSI = f ($L_{tx,160}$, $L_{tx,25}$, $R_{k,TR}$)

Longitudinal Tining

OBSI = f ($L_{tx,40}$)

Diamond Grinding

OBSI = f ($L_{tx,80+63+50+40}$, $Skew_{TR}$)

Drag

OBSI = f ($L_{tx,50+40}$, $Skew_{TR}$, $R_{k,TR}$)

- L_{tx} per ISO/CD 13473-4 (Draft)
- $R_{k,TR(ansverse)}$ per ISO 13565-2
- $Skew_{TR(ansverse)}$ per ASME B46.1

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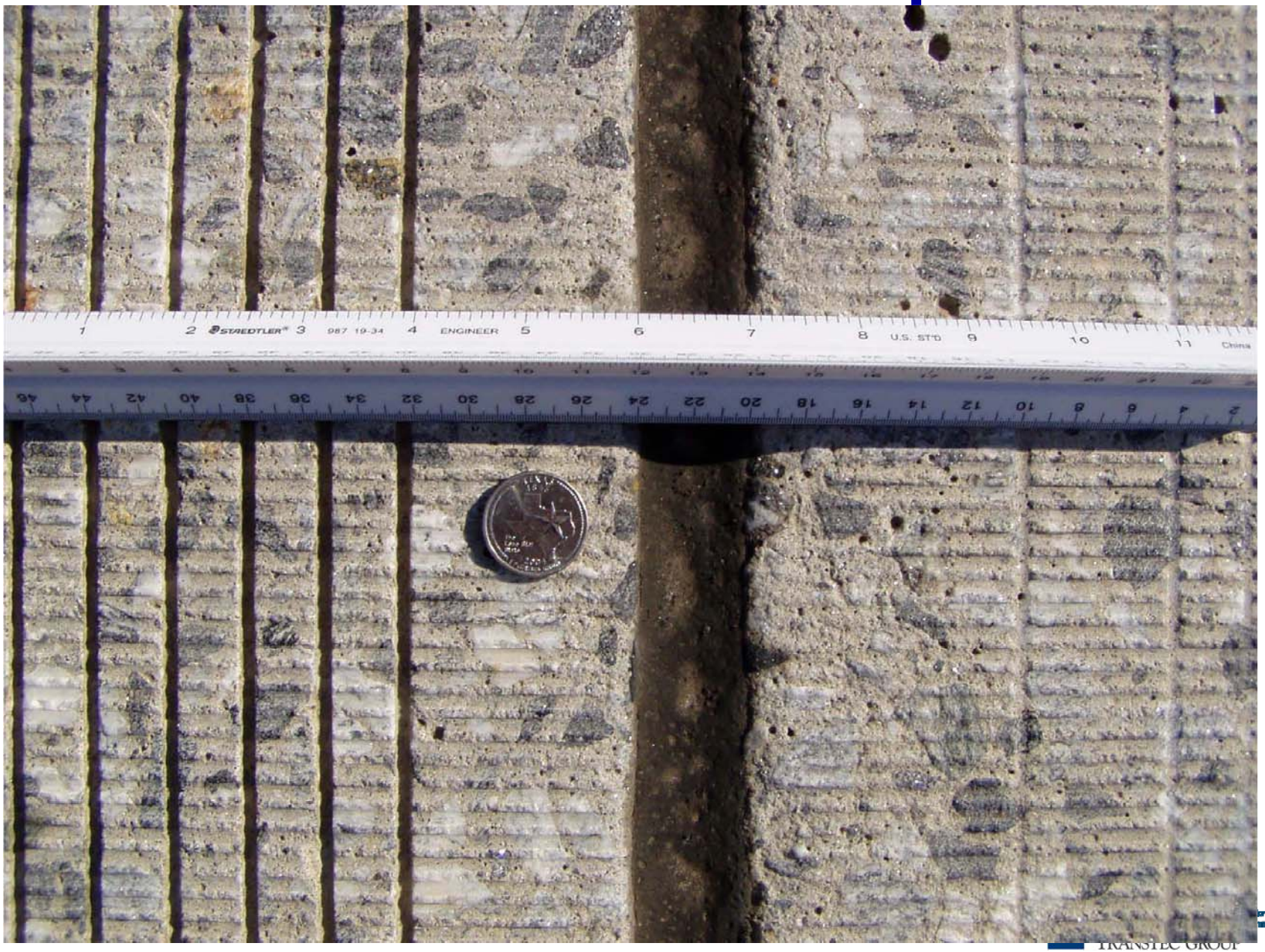
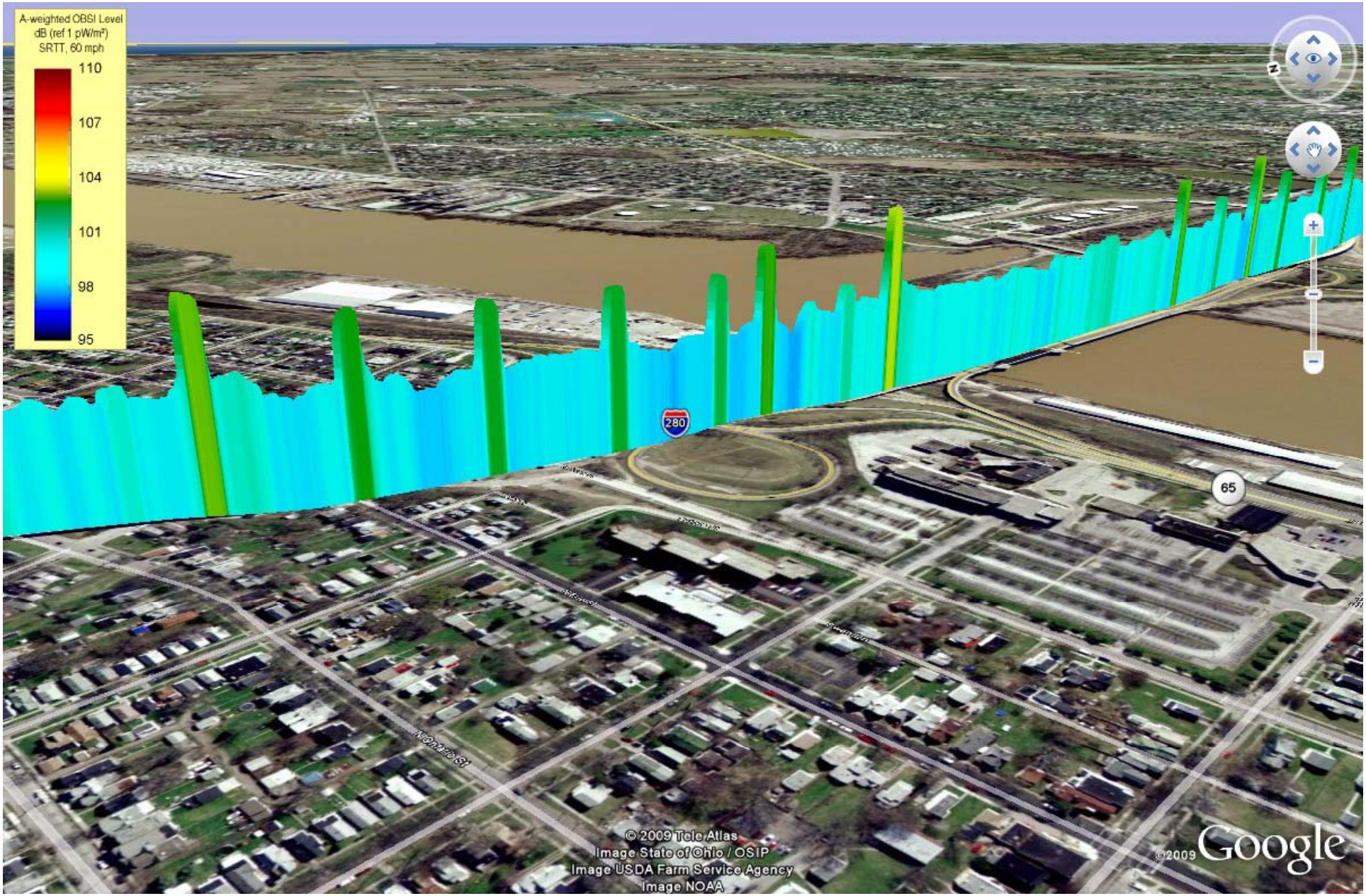
Joint Impulse Noise

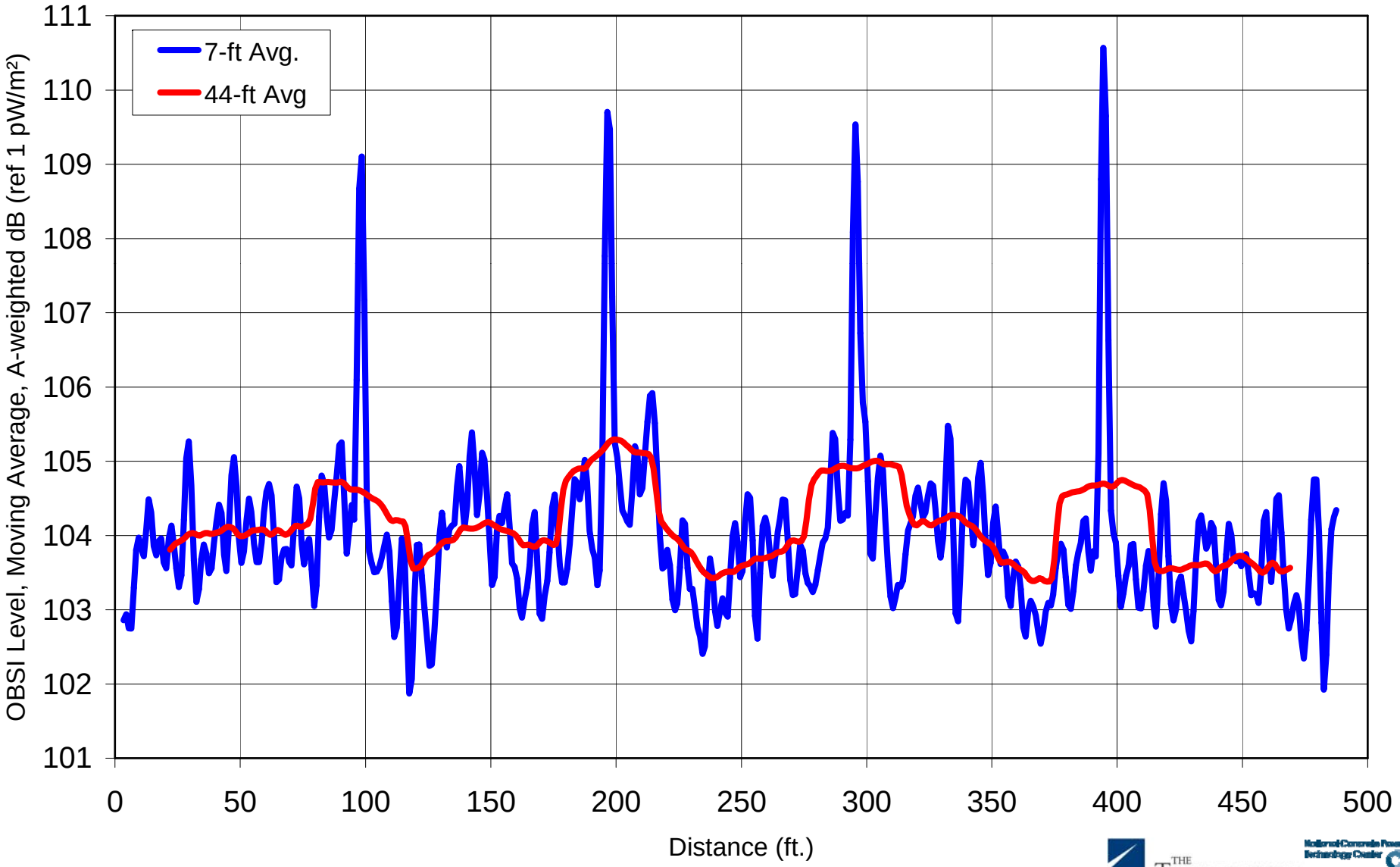


Joint Impulse Noise



Joint Impulse Noise

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



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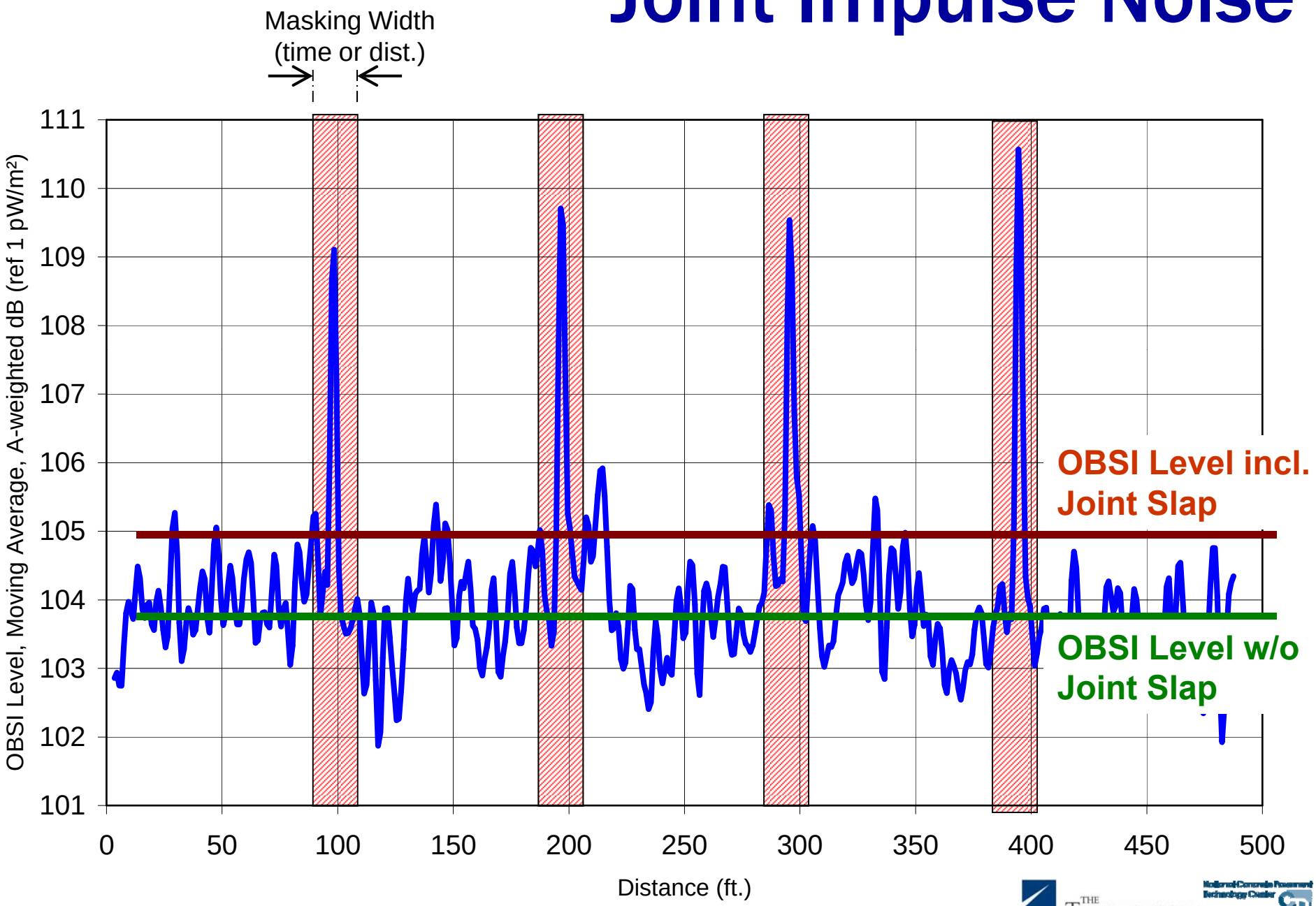
Joint Impulse Noise



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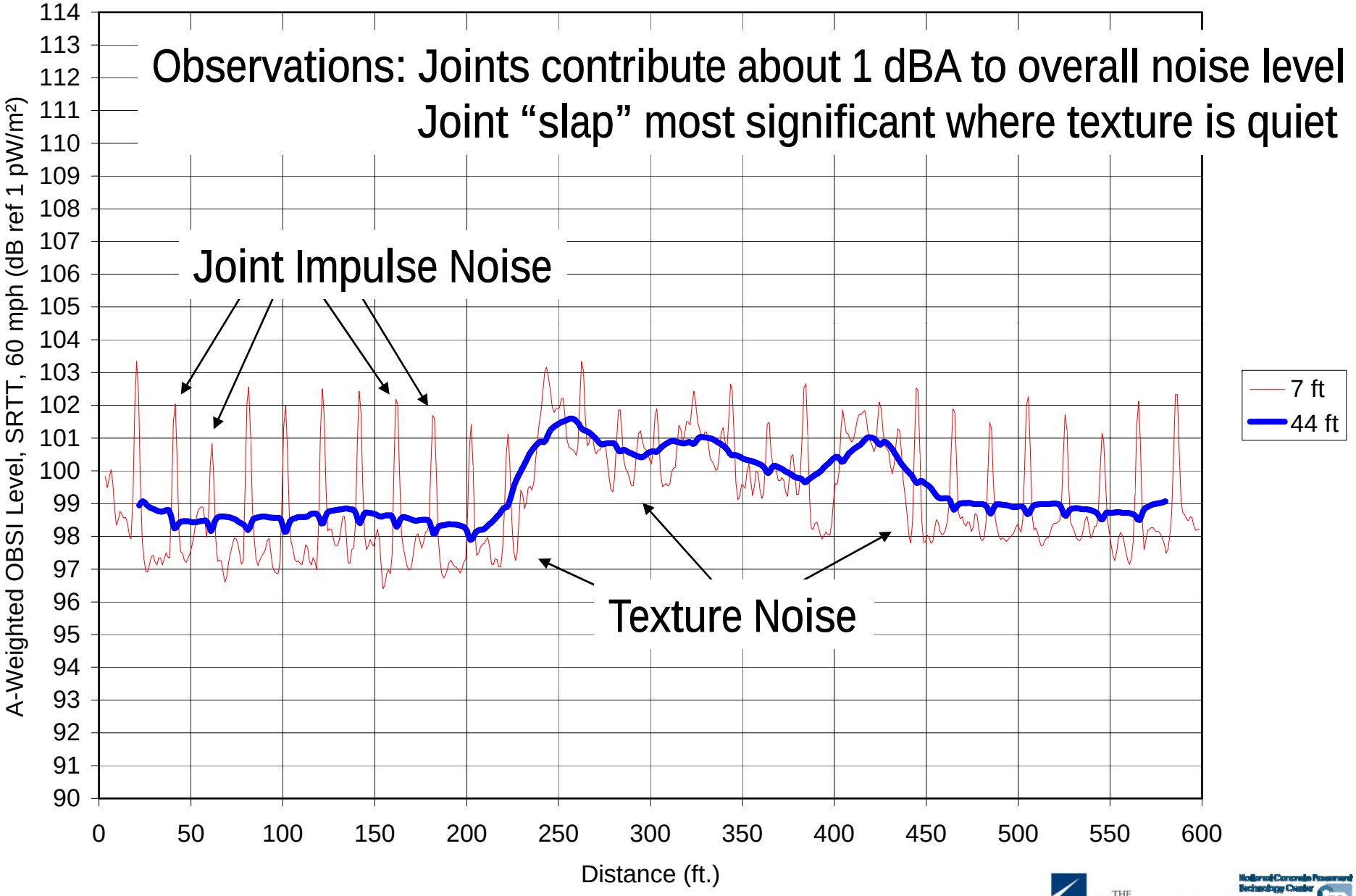
Joint Impulse Noise



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Do you see what I see?

New York (Turf)

104 dBA

Iowa (Burlap)

100 dBA

Drag

Source: National CP Tech Center

Do you see what I see?

Colorado

100 dBA

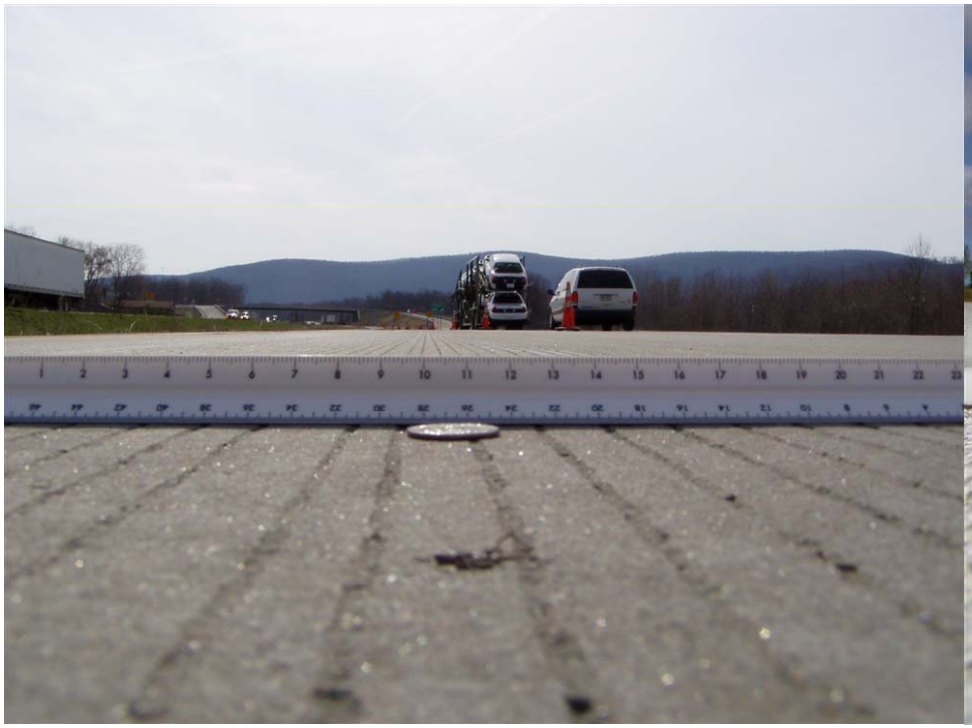
New York

104 dBA

Diamond Grinding

Source: National CP Tech Center

Do you see what I see?



New York

107 dBA

Iowa

101 dBA

Longitudinal Tining

Source: National CP Tech Center

Do you see what I see?

Georgia

102 dBA

Iowa

111 dBA

Transverse Tining

Source: National CP Tech Center