TRB ADC40
June 26, 2018

NCHRP 25-44, FIELD EVALUATION OF REFLECTED NOISE FROM A SINGLE NOISE BARRIER

Bill Bowlby, Ph.D., P.E., Bowlby & Associates, Inc.
Judy Rochat, Ph.D., Cross-Spectrum Acoustics

Research Team and Other Key Personnel

RSG
the science of insight

- Ken Kaliski, P. E. (Project Manager), Karl Washburn and Ryan Haac

Bowlby & Associates, Inc.

- Rennie Williamson, Clay Patton and Darlene Reiter, Ph.D., PE.

ATSConsulting
acoustics, transportation + strategy

- Jack Meighan and Keith Yoerg

ea Environmental Acoustics
Consulting/Design Specialists
Creating Extraordinary & Lasting Sensory Designs

- Ahmed El Aassar, Ph.D., PE., and Harvey Knauer, P.E.

Sanchez Industrial Design Inc

- Gonzalo Sanchez and Doug Barrett (now with Cross-Spectrum Acoustics)

Motivation for the Research

- State highway agencies have received complaints from residents living across the road from single noise barriers
- Change in perceptibility seems to be greater than expected small increase in the A-weighted equivalent sound level due to reflections

Sound-reflecting barrier on MD-5, Maryland

Objectives

- Determine spectral sound level characteristics opposite a single noise barrier through field measurements
  - Sound-reflecting barriers
  - Sound-absorbing barriers
- Analyze and summarize implications of results for better understanding of actual and perceived effects of reflected noise

Tasks

- Literature review (appendix to final report)
- Data collection/analysis at five sound-reflecting barrier locations
  - NCHRP Web Document 218
- Data collection/analysis at three sound-absorbing barrier locations
- Reflections screening tool
- Layperson's guide
- Amended report, appendices and presentation
  - To be published in Q3 as NCHRP Report 886

Sound-reflecting Barrier Locations

Location	Road	City, State	Lanes	Pavement Type	Road Cross Section	Traffic Volume (veh/day)	Barrier Location	Barrier Height at Study Site (ft)
ATS-3	SR-71	Chino Hills, CA	6	Concrete	At-Grade	60,000	ROW	13 (7-ft wall atop 6-ft berm)
BA-1	I-24	Murfreesboro, TN	8	Asphalt	At-Grade (slight fill)	78,140	ROW	16-19
BA-3	Briley Pkwy	Nashville, TN	6	Asphalt	Fill (Retaining Wall)	45,820	Shoulder	12-13
EA-5	MD Route 5	Hughesville, MD	4	Asphalt	At-Grade	34,160	Shoulder	16
SID-1	I-90	Rockford, IL	6	Asphalt	At-Grade	53,470	Shoulder	15

SR-71, CA

I-24, TN

I-90, IL

Sound-absorbing Barrier Locations

Location	Road	City, State	Lanes	Pavement Type	Road Cross Section	Daily Traffic (vehicles/day) and Year	Barrier Location	Barrier Material	Barrier Height at Study Site (ft)
OH-1	I-75	Troy, Ohio	6	PCC	At-Grade	63,273 (2015)	ROW	Concrete with rubber tire chip sound-absorbing face	16-18 ft
OH-2	I-70	South Vienna, Ohio	6	DGAC	Slight cut	45,923 (2015)	ROW	Concrete with rubber tire chip sound-absorbing face	18-20 ft
OH-3	I-270	Grove City, Ohio	6	PCC	At-Grade	63,768 (2015)	EOP	Concrete / wood fiber aggregate sound-absorbing face	14-16 ft

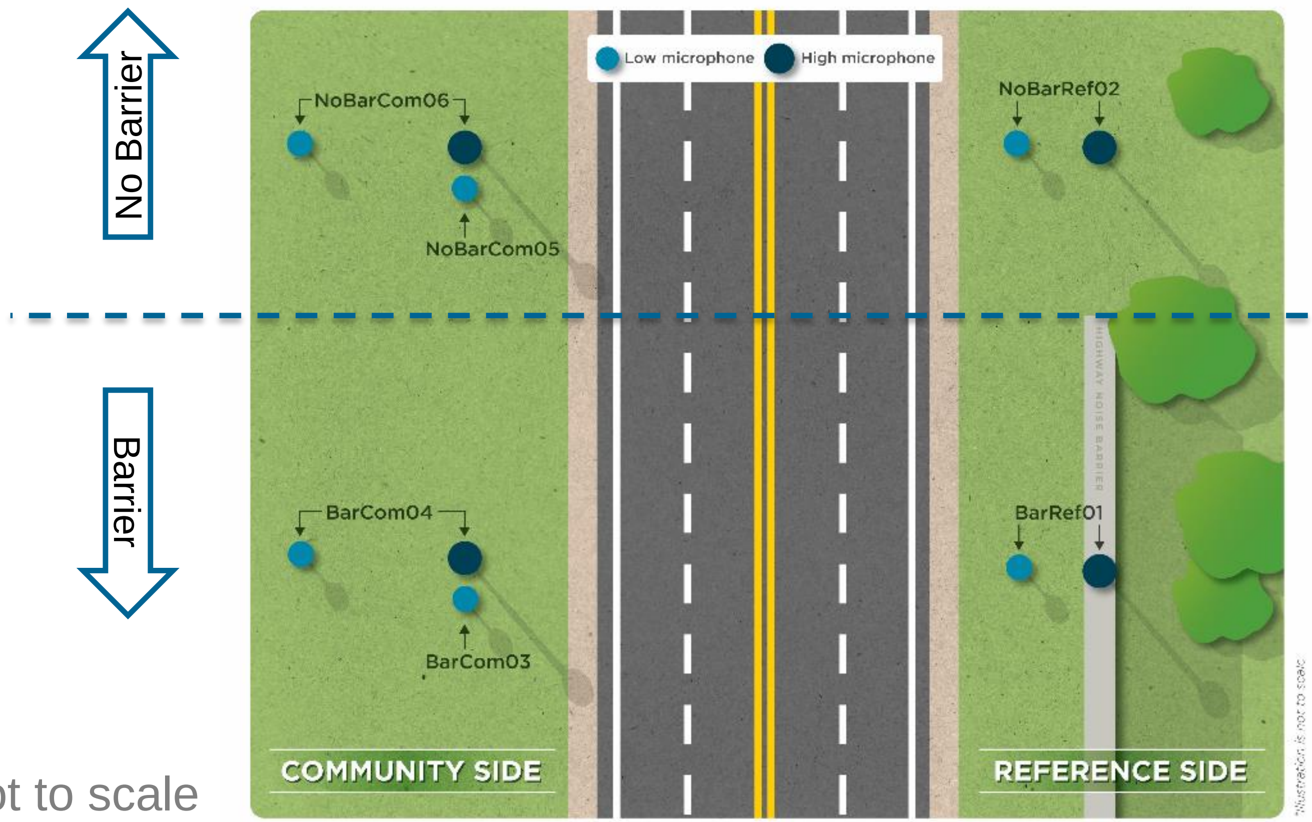
I-75, OH

I-70, OH

I-270, OH

Microphone Designation and Placement

Site	Reference Mic	Low or Near Mic	High or Far Mic
Barrier	BarRef01	BarCom03	BarCom04
No Barrier	NoBarRef02	NoBarCom05	NoBarCom06



Not to scale

Data Collection Protocol

- Attended monitoring for 4 hours of 1-sec, 1/3-octave band data at each mic, plus audio
- Traffic counts from video
- Speed data using laser gun
- Wind and temperature data at 5 ft and 15 ft

Data Analysis: Adapted FHWA's Indirect Measured Method for Determining Insertion Loss

- Based on simultaneous measurements at Barrier site and equivalent No Barrier site
- Studied groups of 5-minute periods equivalent in terms of:
  - Source
  - Meteorology
    - Wind class (Upwind, Downwind, Calm)
    - Temperature class (Lapse, Neutral, Inversion)
- L_{eq} differences (broadband and 1/3-octave band)
- Also, L_{90} and L_{99} differences as indicators of effects on background levels (broadband and 1/3-octave band)

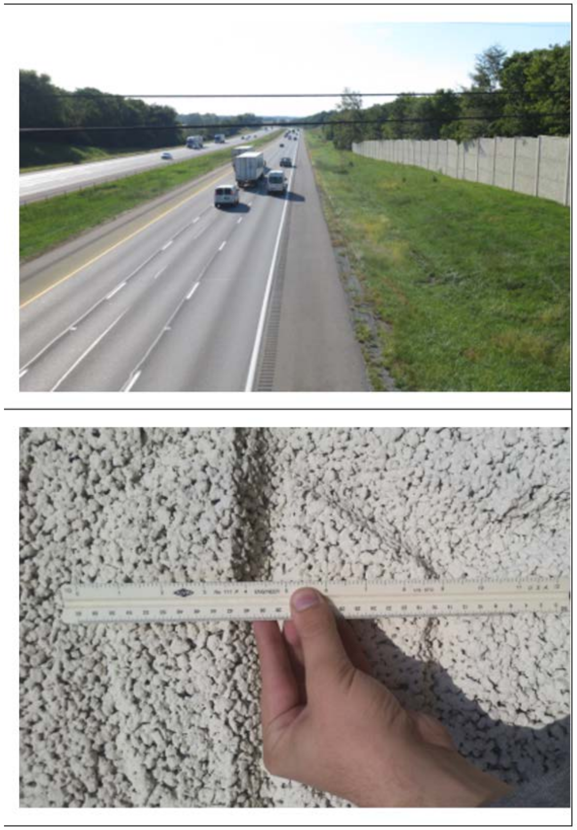
Additional Data Analysis

- Acoustical spectrograms
- Difference spectrograms and comb-filtering analysis
- Psychoacoustic metrics of loudness, sharpness, roughness, and fluctuation strength combined into metrics of annoyance (only for sound-reflecting barriers)

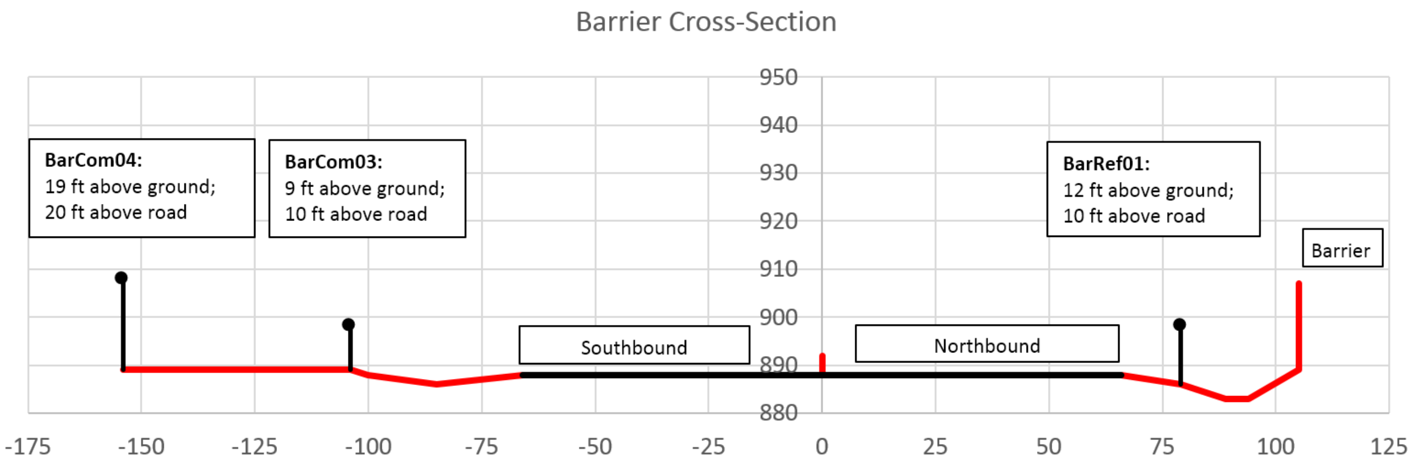
Findings for Sound-reflecting Barriers

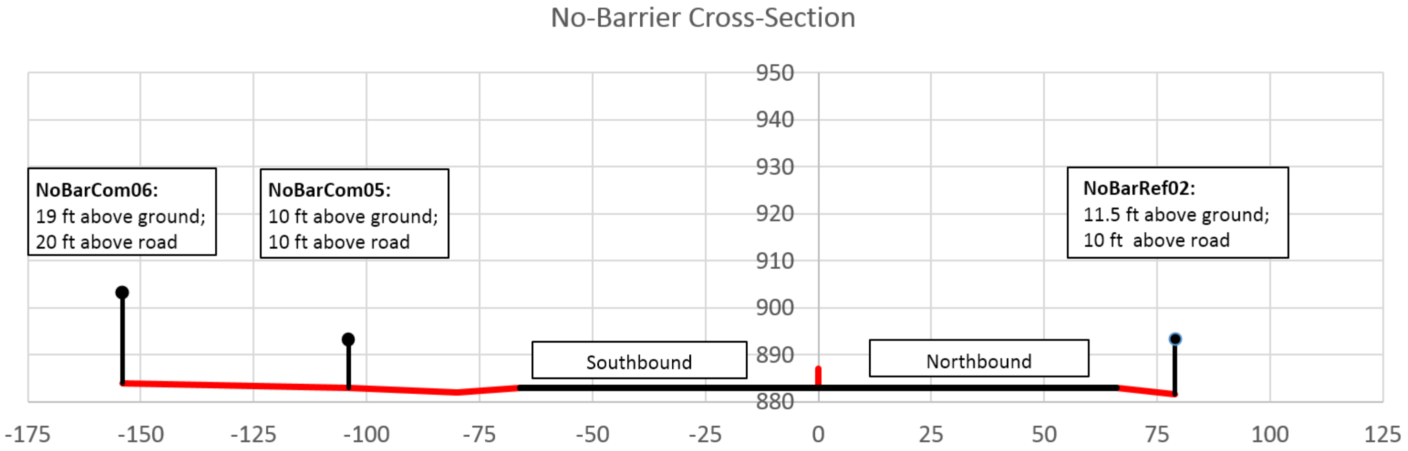
- Compared to equivalent No Barrier site…
  - Broadband L_{eq} are 1-2 dB higher
  - Mid-range frequency sound pressure levels are enhanced
  - Background sound levels increase more than L_{eq}, suggesting pass-by sound is being sustained
- Spectrograms show frequency- and time-broadening of pass-by sound due to reflected noise
- Simple psychoacoustic annoyance metrics do not reliably demonstrate annoyance increases

Sound-Absorbing Barriers: I-75 (left, Noise Reduction Coefficient (NRC) =0.80); I-70 (middle, NRC=0.80); I-270 (right, NRC=0.85)

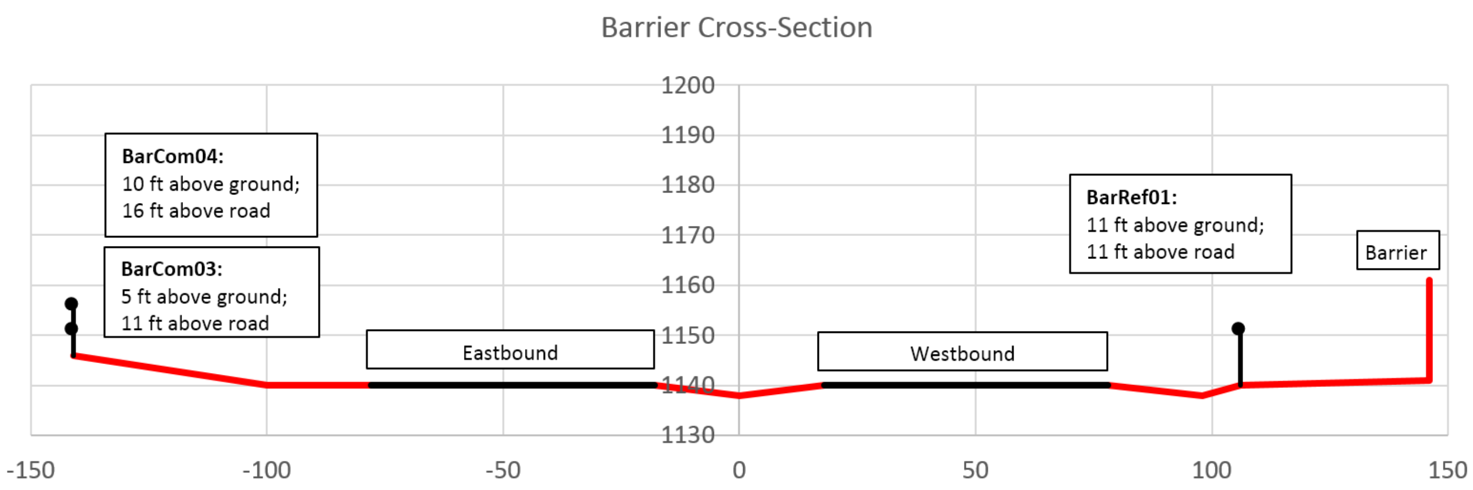


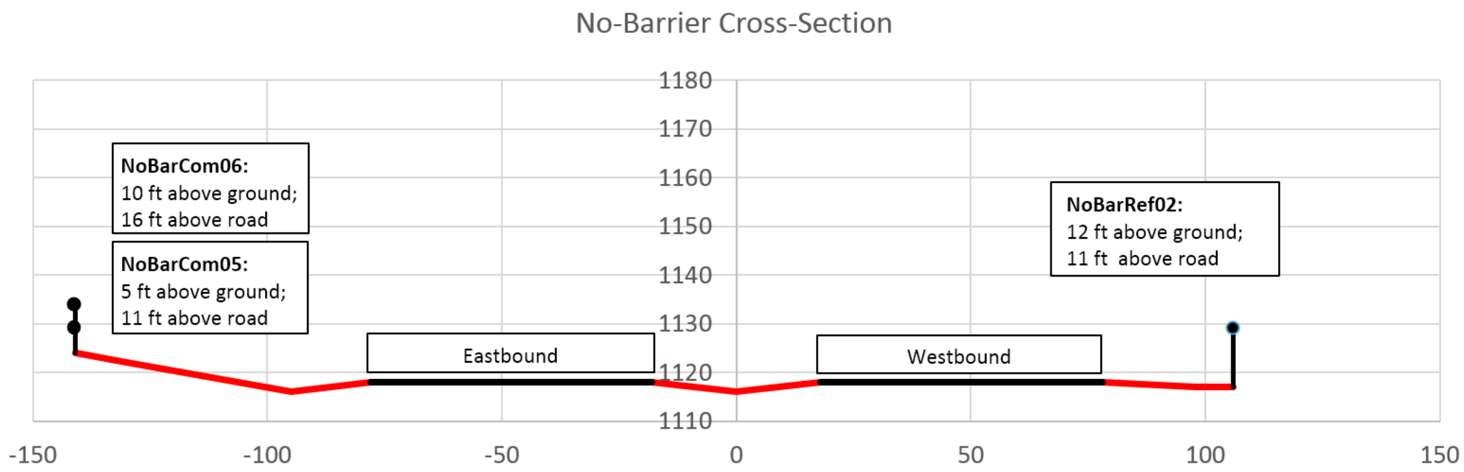
I-75 Cross-sections: Barrier and No Barrier sites





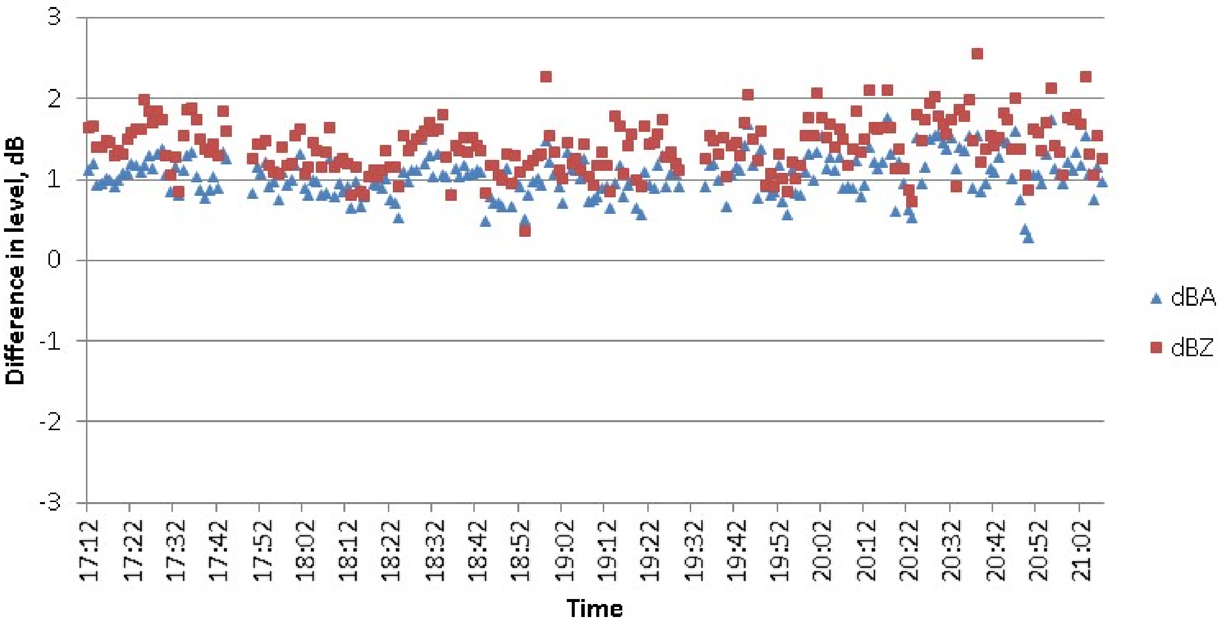
I-70 Cross-sections:
Barrier and No Barrier sites





Sound-absorbing Barrier Comparison Findings: I-75 Broadband, Same Side of Road

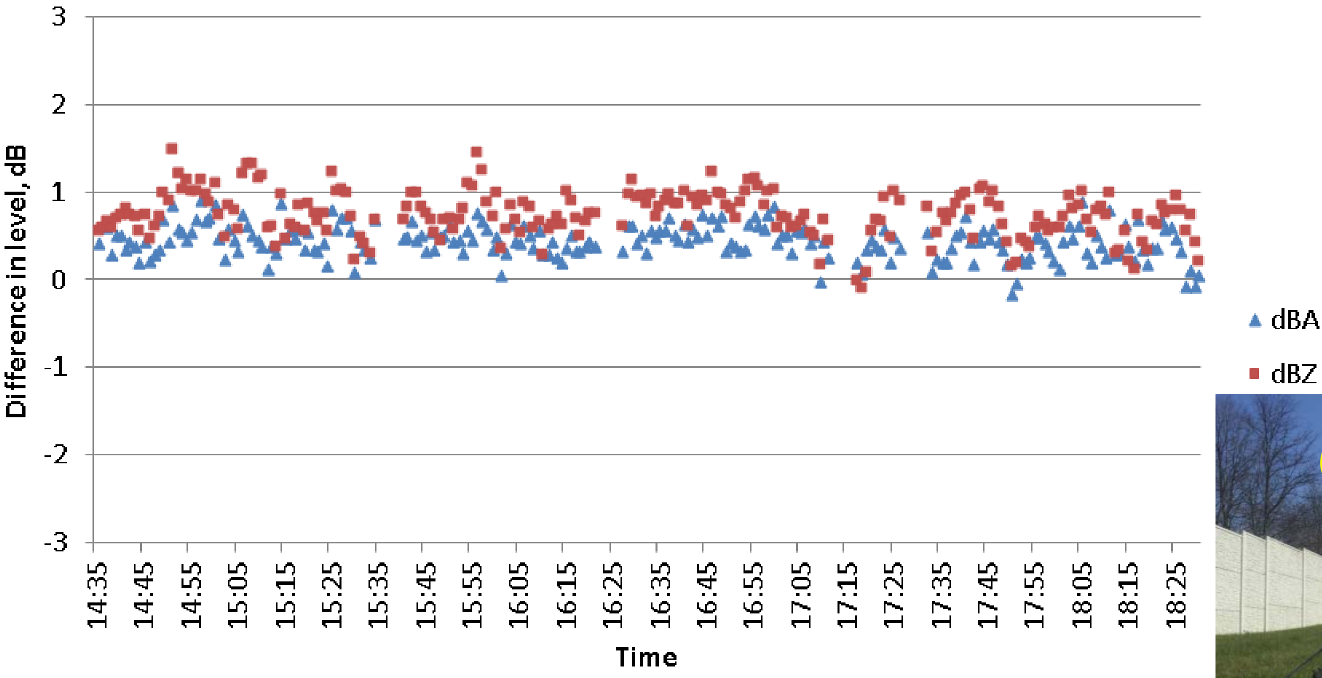
- Differences are seen in broadband 5-min L_{eq} at reference mics between the road and barrier
- Similar to sound-reflecting barriers



I-75, OH

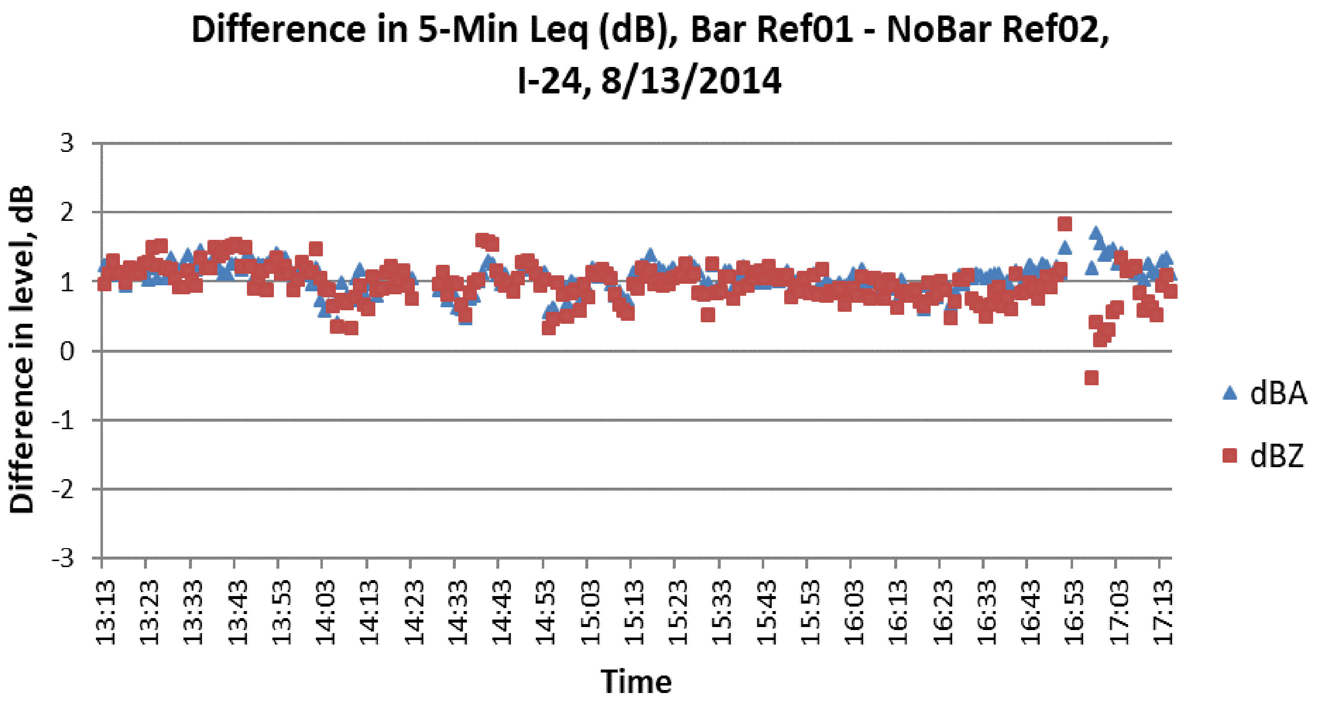
Differences in running L_{eq}(5min), I-75, BarRef01 minus NoBarRef02

I-70 (Sound-absorbing): Broadband, Same Side of Road



I-70 OH

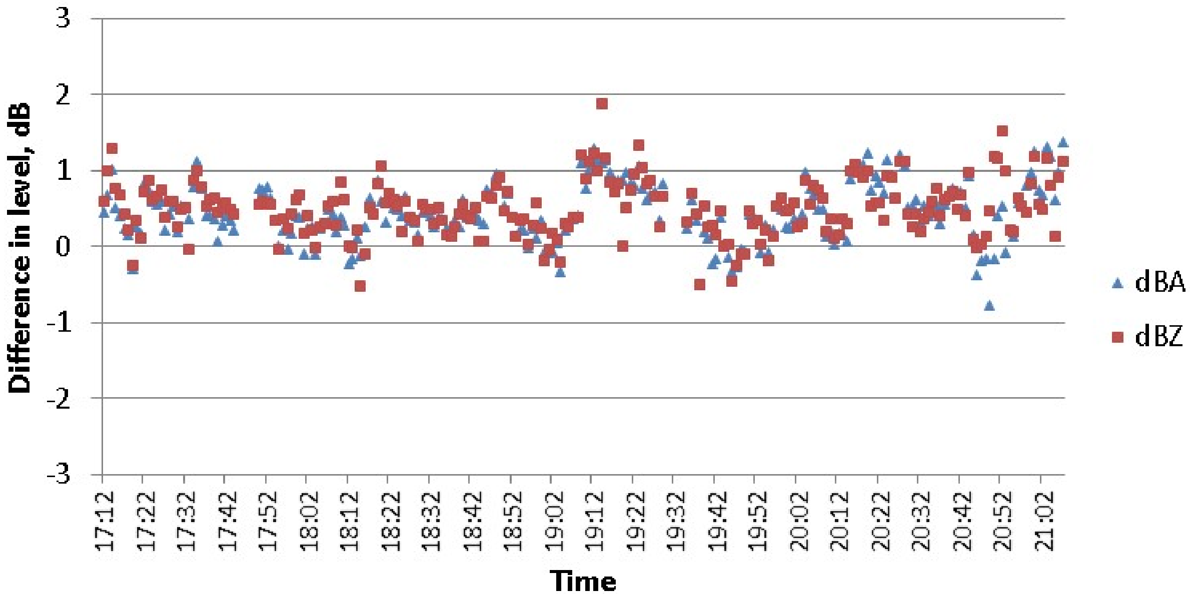
I-24 (Sound-reflecting): Broadband, Same Side of Road



I-24, TN

Sound-absorbing Barrier Comparison Findings: I-75 Broadband, Community Side

- Broadband L_{eq} average about 0.5 dB higher opposite sound-absorbing barrier compared to No Barrier site at 50 and 100 ft from road (shown is 100 ft)
- Increase is less than at sound-reflecting barriers at the farther distances

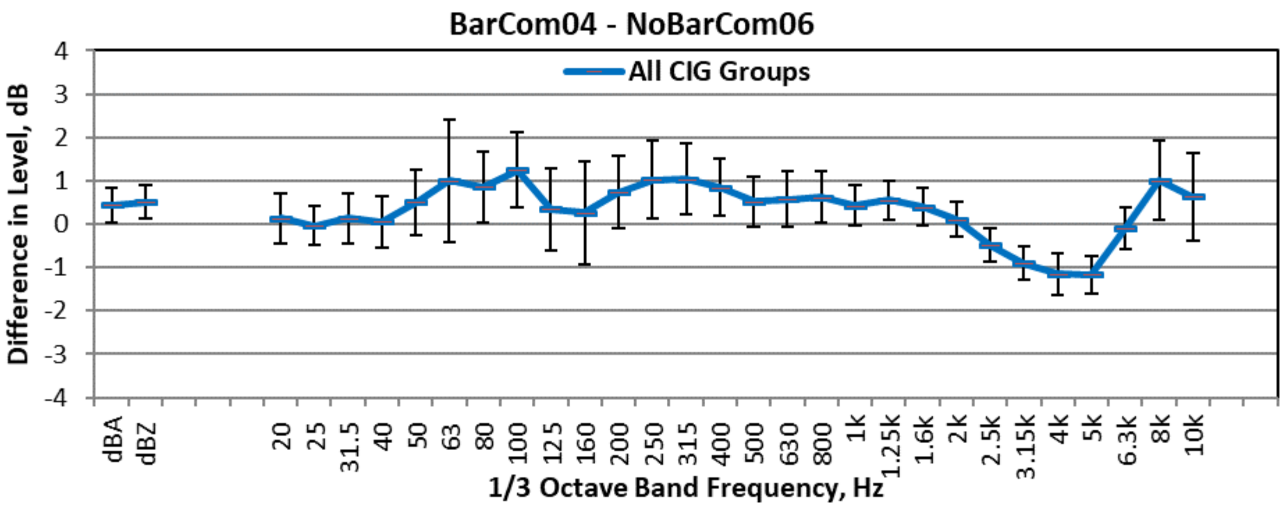


Differences in running L_{eq}(5min), I-75, BarCom04 minus NoBarCom06

I-75, OH

Sound-absorbing Barrier Comparison Findings: I-75 1/3-octave, Community Side

- 1/3-octave band levels are slightly higher opposite sound-absorbing barrier compared to No Barrier site for mics at 50 and 100 ft from I-75
- Differences at the 100-ft distance (below) were less than at sound-reflecting barriers

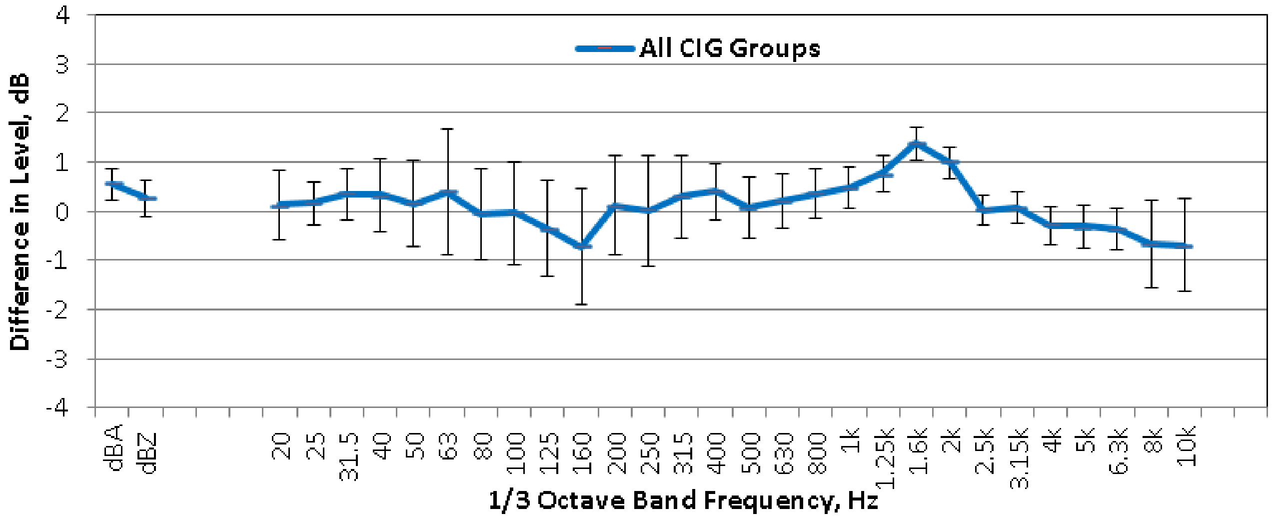


Averages of the differences in L_{eq}(5min), BarCom04 minus NoBarCom06, for all Calm Inversion groups, I-75

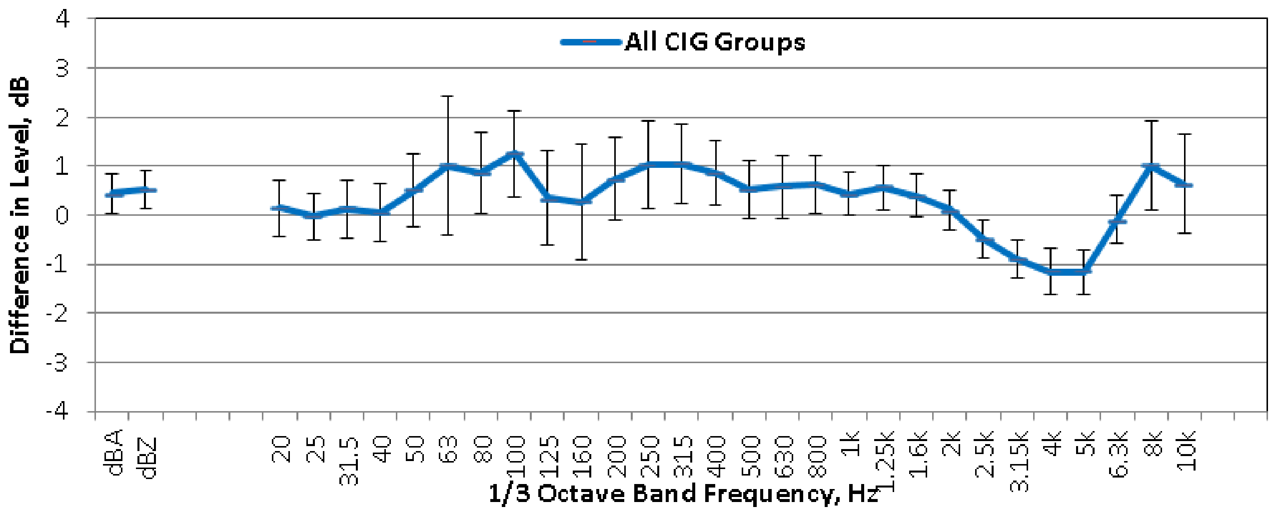
I-75, OH

I-75: Differences at Both Community Mics

50 ft from road

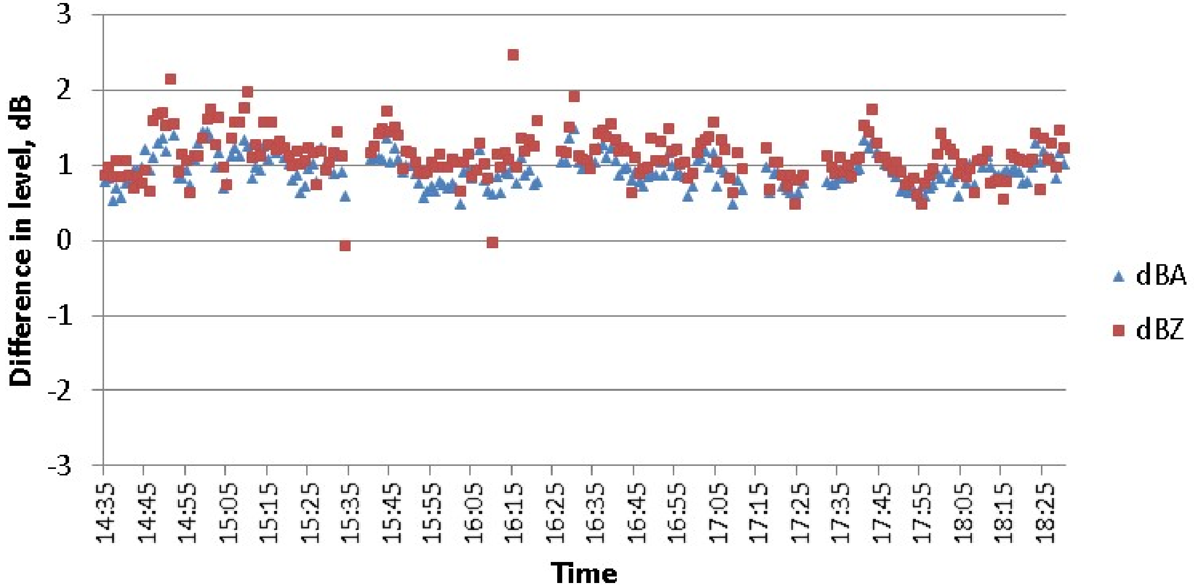


Same as previous slide - 100 ft from road



Sound-absorbing Barrier Comparison Findings: I-70 Broadband, Community Side

- Broadband L_{eq} average about 1 dB higher opposite the sound-absorbing barrier compared to No Barrier L_{eq} for both mic heights
- Similar to reflective barriers

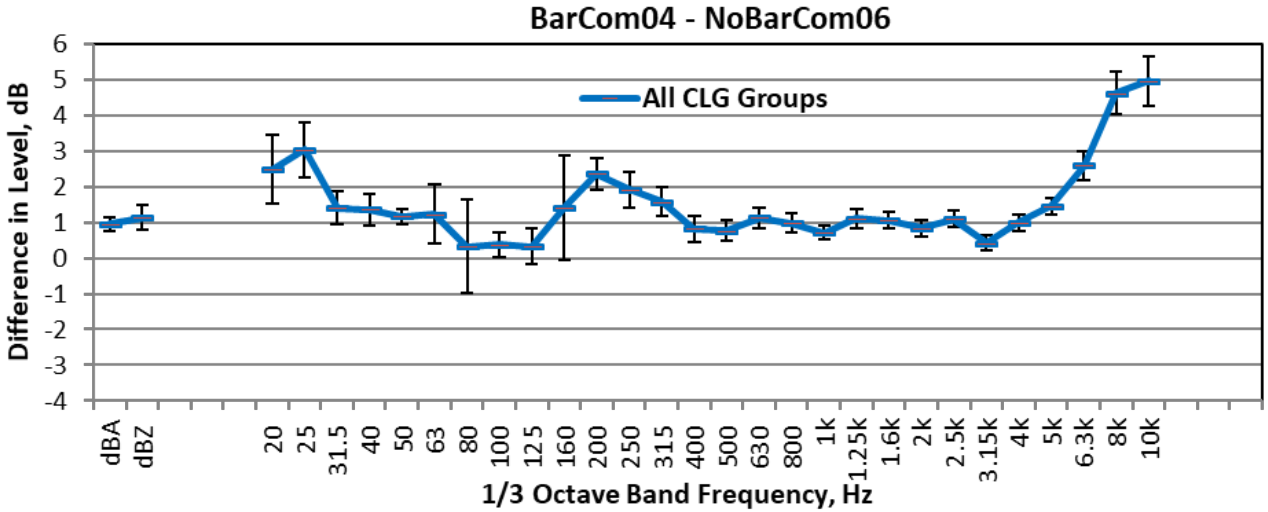


Differences in running L_{eq}(5min), I-70, BarCom04 minus NoBarCom06

I-70, OH

Sound-absorbing Barrier Comparison Findings: I-70 1/3-octave, Community Side

- 1/3-octave band levels are slightly higher opposite the sound-absorbing barrier than at No Barrier site, with less effect at upper mic (shown below)
- Differences are similar to sound-reflecting barriers

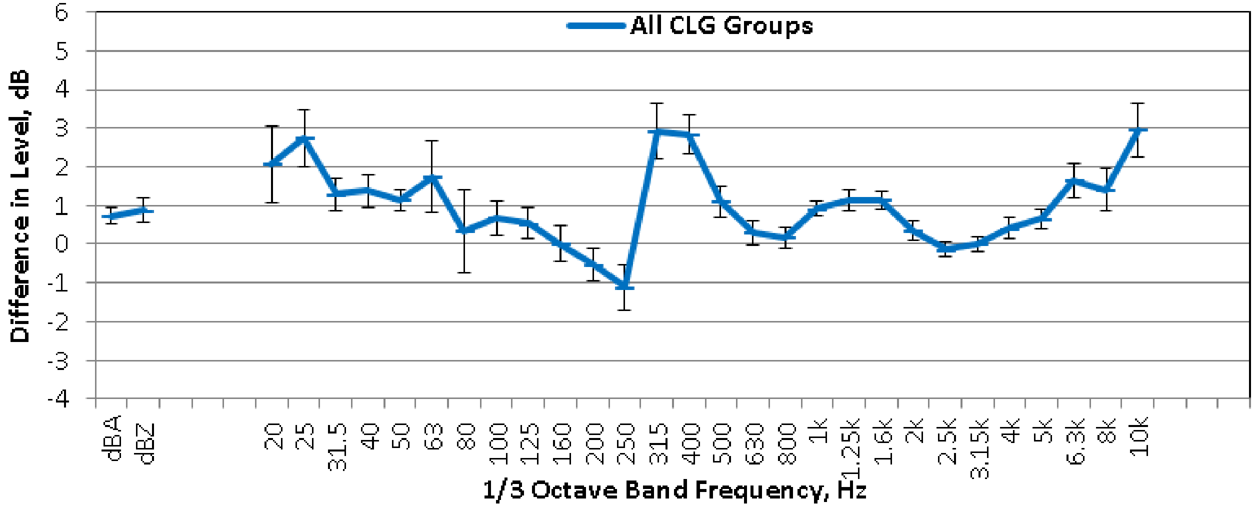


Averages of the differences in L_{eq}(5min), BarCom04 minus NoBarCom06 for all Calm Lapse groups, I-70

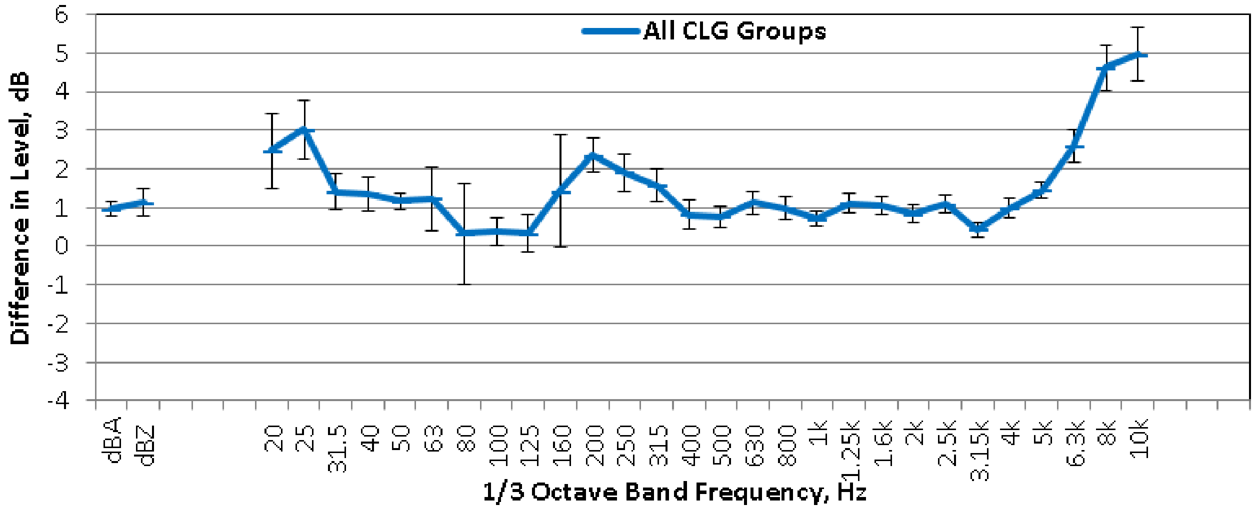
I-70, OH

I-70: Differences at Lower and Upper Community Mics

Lower mic

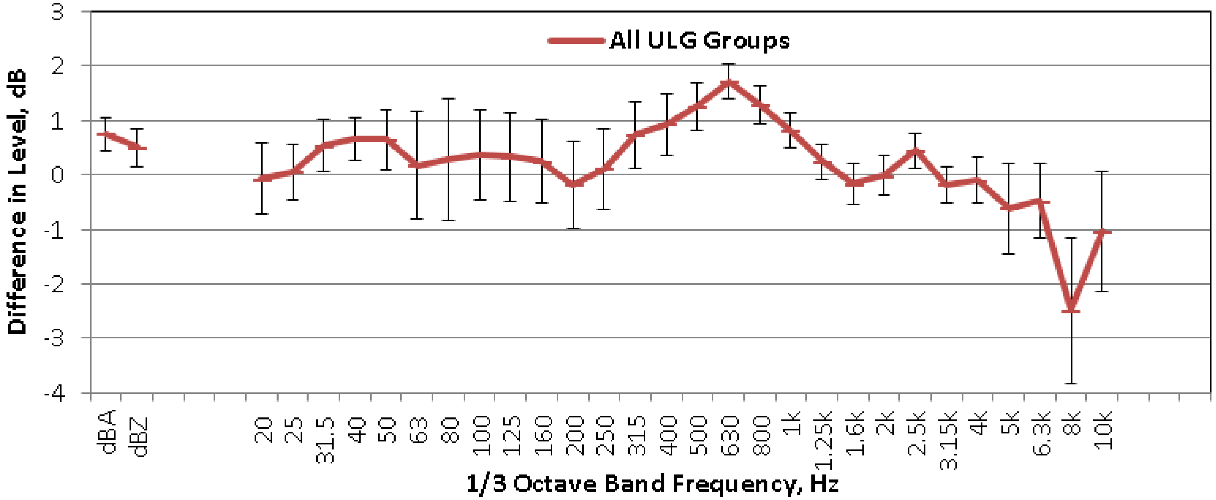


Same as previous slide - Upper mic

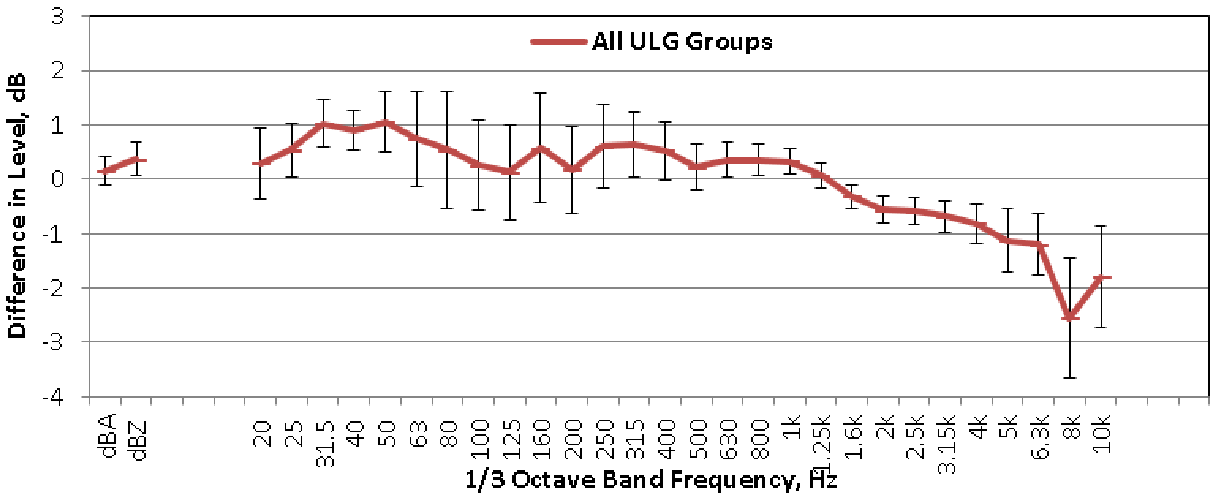


I-24 (Sound-reflecting): Differences at Lower and Upper Community Mics

Lower mic

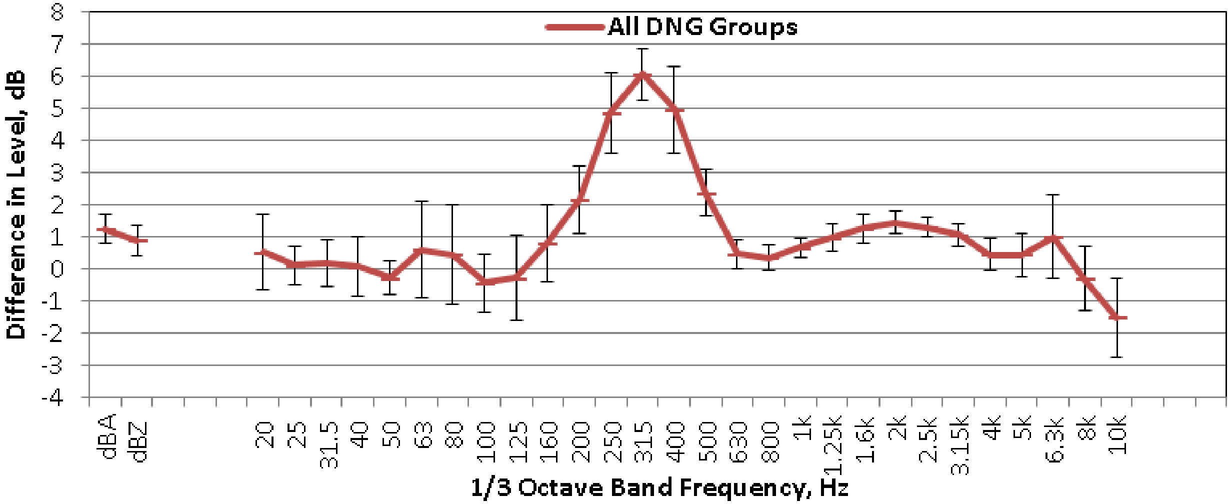


Upper mic

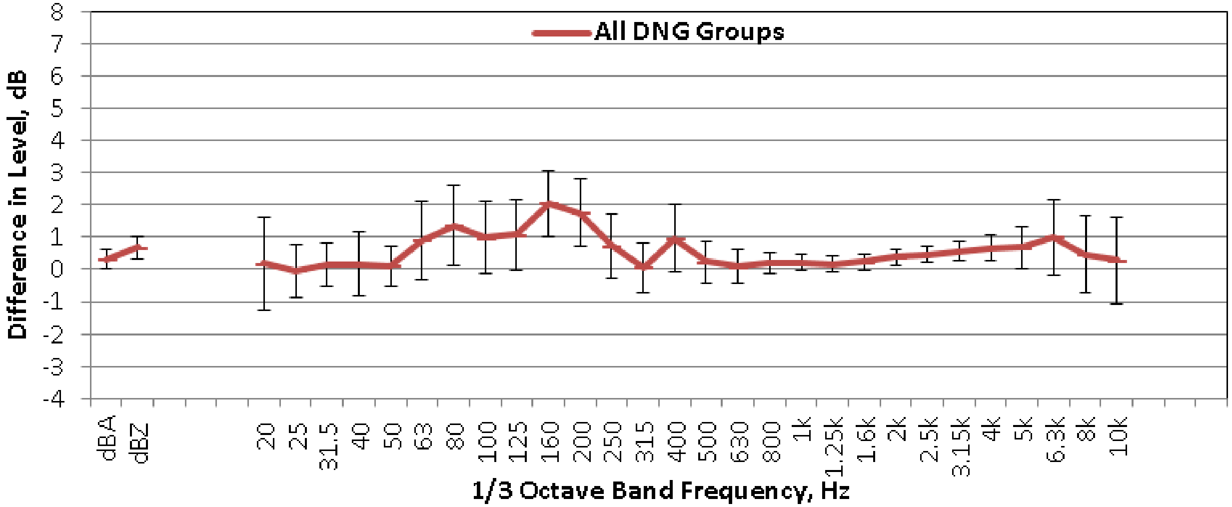


MD-5 (Sound-reflecting): Differences at Lower and Upper Community Mics

Lower mic

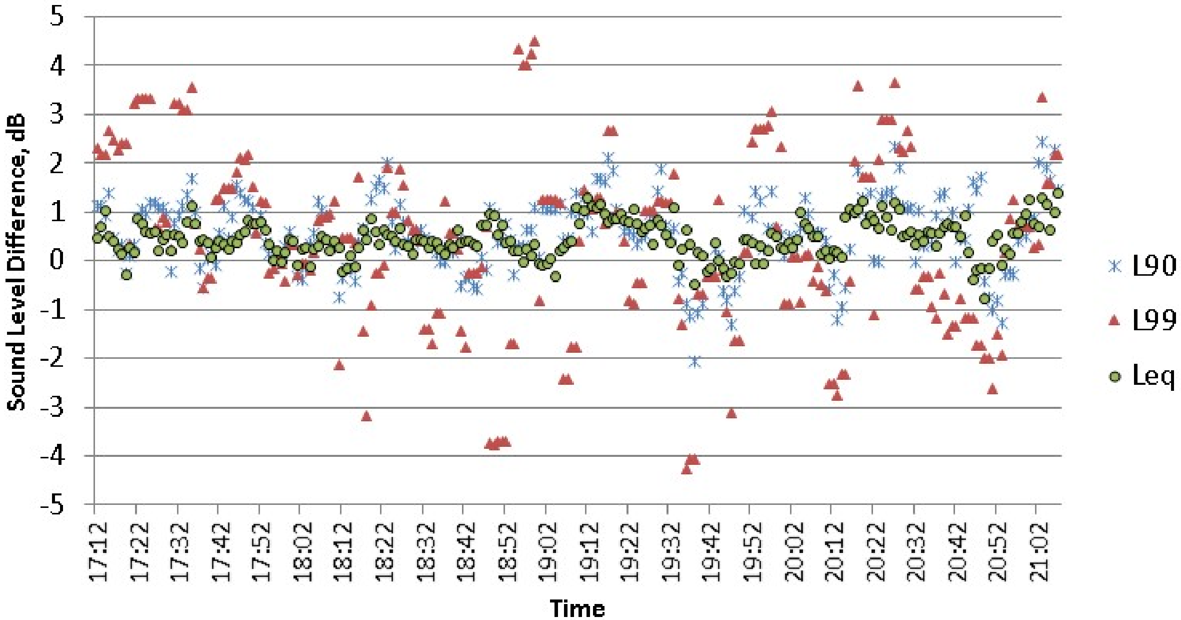


Upper mic



Sound-absorbing Barrier Comparison Findings: I-75 Broadband L_{90} and L_{99}

- Broadband L_{90} and L_{99} differences at both mic distances across from the sound-absorbing barrier show no pattern of being greater than L_{eq} differences (shown is 100-ft)
- Unlike at the sound-reflecting barriers

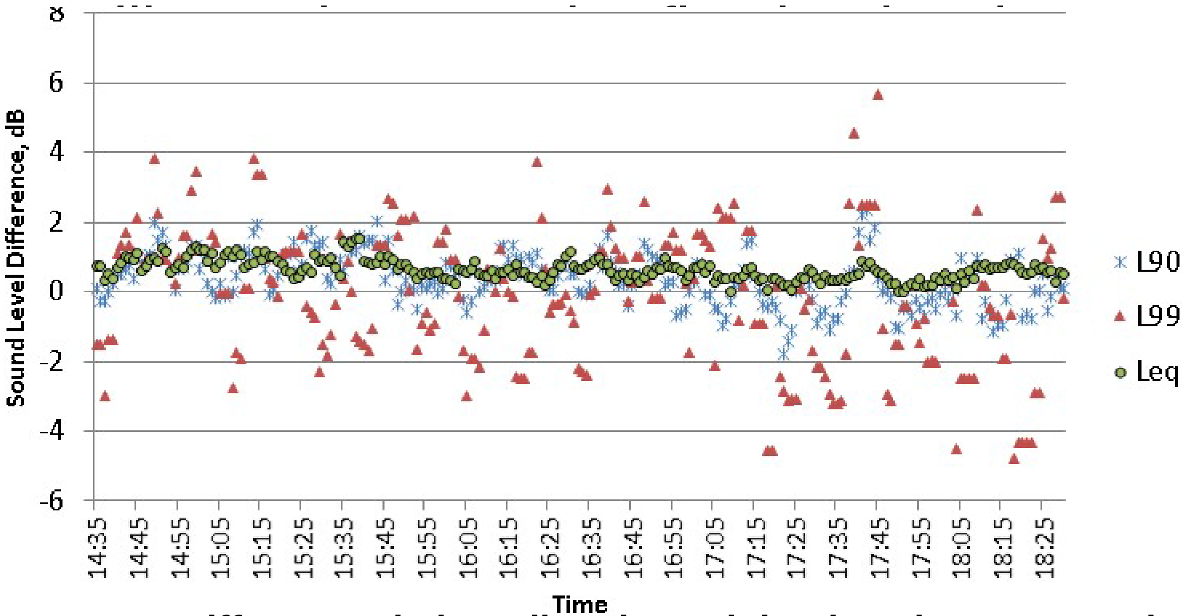


Differences in broadband A-weighted 5-min L_{90}, L_{99} and L_{eq}, I-75, BarCom04 minus NoBarCom06

I-75, OH

Sound-absorbing Barrier Comparison Findings: I-70 Broadband L_{90} and L_{99}

- Broadband L_{90} and L_{99} differences at both mic heights across from the sound-absorbing barrier show no pattern of being greater than L_{eq} differences (shown is lower mic)

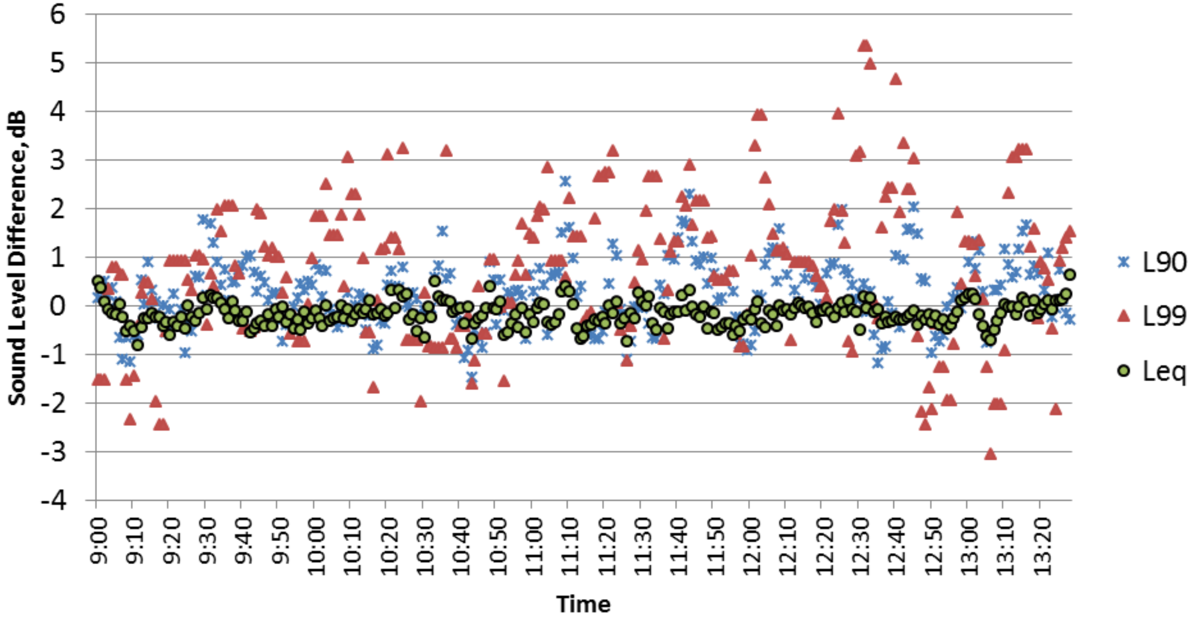


Differences in broadband A-weighted 5-min L_{90}, L_{99} and L_{eq}, I-70, BarCom03 minus NoBarCom05

I-70, OH

SR-71 (Sound-reflecting): Broadband L_{90} and L_{99}

- There is an increase in background A-weighted sound levels at the Barrier site (mic near the road), but no increase in L_{eq}



SR-71, CA

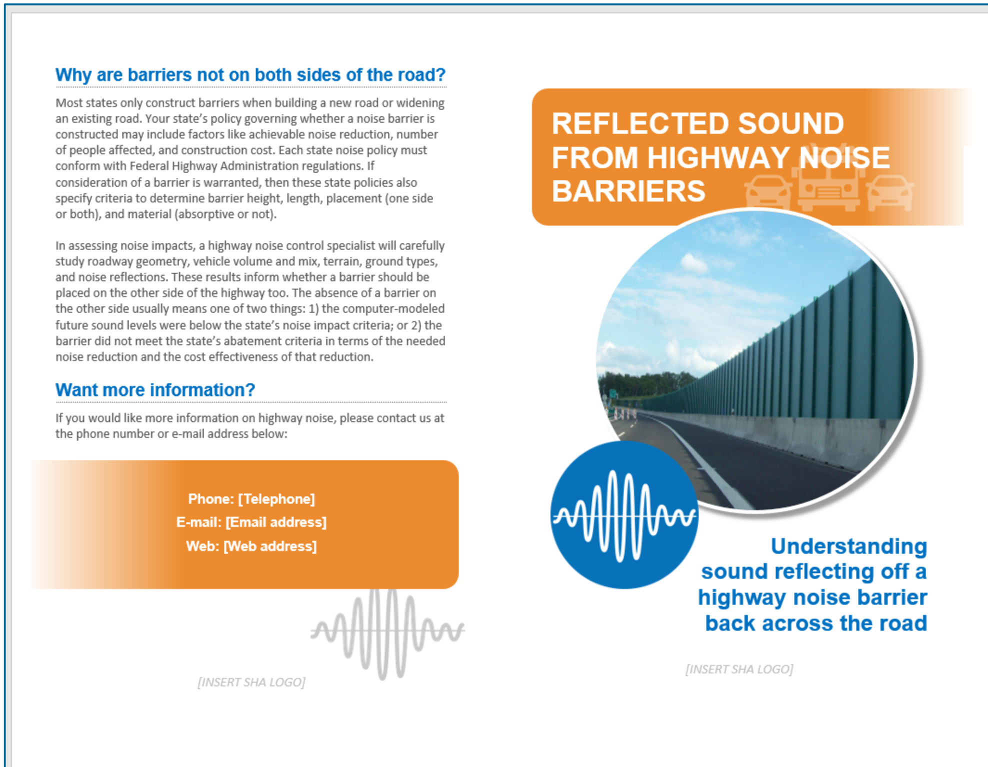
Differences in broadband A-weighted 5-min L_{90}, L_{99} and L_{eq}, SR-71, BarCom03 minus NoBarCom05.

Conclusions for Sound-absorbing Barriers using FHWA Indirect Measured Method

For an NRC of 0.80 – not generalized to all sound-absorbing barriers

- Broadband A-weighted and unweighted L_{eq} show a small increase over No Barrier site
- Some enhancing of mid-range frequency sound pressure levels compared to No Barrier site
- Background sound levels opposite the barrier do not increase more than the L_{eq} increases when compared to No Barrier site, suggesting no sustaining of pass-by sounds

Layperson's Guide – Customizable Word File



Why are barriers not on both sides of the road?

Most states only construct barriers when building a new road or widening an existing road. Your state's policy governing whether a noise barrier is constructed may include factors like achievable noise reduction, number of people affected, and construction cost. Each state noise policy must conform with Federal Highway Administration regulations. If consideration of a barrier is warranted, then these state policies also specify criteria to determine barrier height, length, placement (one side or both), and material (absorptive or not).

In assessing noise impacts, a highway noise control specialist will carefully study roadway geometry, vehicle volume and mix, terrain, ground types, and noise reflections. These results inform whether a barrier should be placed on the other side of the highway too. The absence of a barrier on the other side usually means one of two things: 1) the computer-modeled future sound levels were below the state's noise impact criteria; or 2) the barrier did not meet the state's abatement criteria in terms of the needed noise reduction and the cost effectiveness of that reduction.

Want more information?

If you would like more information on highway noise, please contact us at the phone number or e-mail address below:

Phone: [Telephone]
E-mail: [Email address]
Web: [Web address]

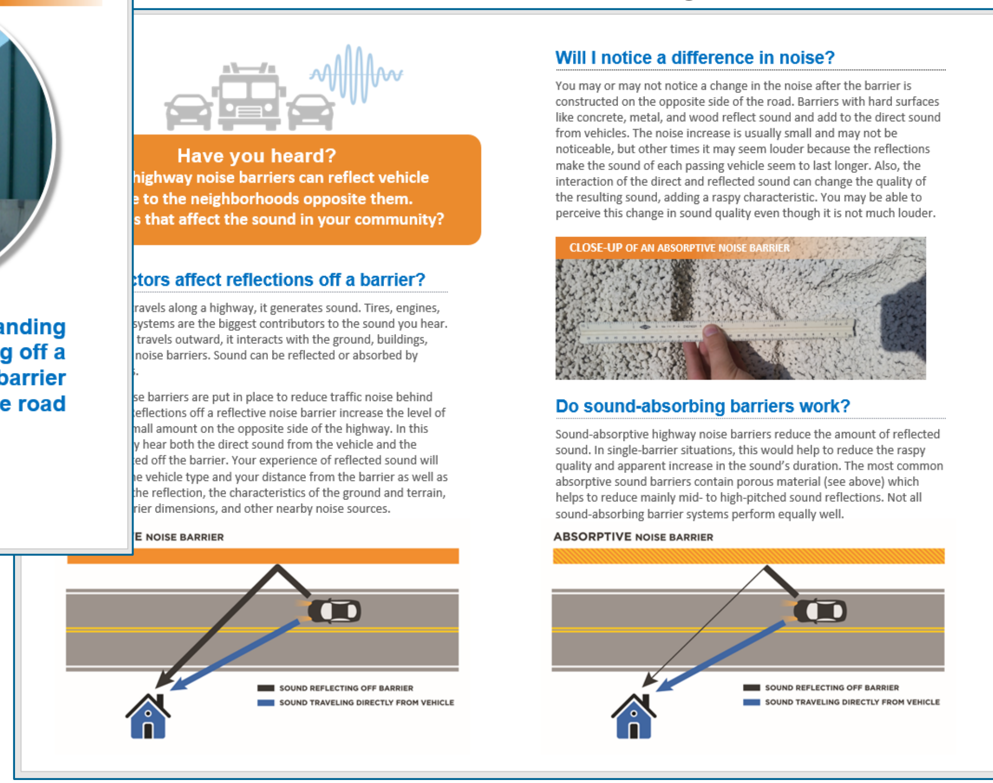
[INSERT SHA LOGO]

REFLECTED SOUND FROM HIGHWAY NOISE BARRIERS

Understanding sound reflecting off a highway noise barrier back across the road

[INSERT SHA LOGO]

- What factors affect reflections off a barrier?
- Will I notice a difference in noise?
- Do sound-absorbing barriers work?



Have you heard?
highway noise barriers can reflect vehicle
e to the neighborhoods opposite them.
s that affect the sound in your community?

ctors affect reflections off a barrier?

ravels along a highway, it generates sound. Tires, engines, systems are the biggest contributors to the sound you hear. travels outward, it interacts with the ground, buildings, noise barriers. Sound can be reflected or absorbed by .

se barriers are put in place to reduce traffic noise behind eflections off a reflective noise barrier increase the level of nall amount on the opposite side of the highway. In this y hear both the direct sound from the vehicle and the ed off the barrier. Your experience of reflected sound will e vehicle type and your distance from the barrier as well as the reflection, the characteristics of the ground and terrain, rier dimensions, and other nearby noise sources.

E NOISE BARRIER

SOUND REFLECTING OFF BARRIER
SOUND TRAVELING DIRECTLY FROM VEHICLE

Will I notice a difference in noise?

You may or may not notice a change in the noise after the barrier is constructed on the opposite side of the road. Barriers with hard surfaces like concrete, metal, and wood reflect sound and add to the direct sound from vehicles. The noise increase is usually small and may not be noticeable, but other times it may seem louder because the reflections make the sound of each passing vehicle seem to last longer. Also, the interaction of the direct and reflected sound can change the quality of the resulting sound, adding a raspy characteristic. You may be able to perceive this change in sound quality even though it is not much louder.

CLOSE-UP OF AN ABSORPTIVE NOISE BARRIER

Do sound-absorbing barriers work?

Sound-absorptive highway noise barriers reduce the amount of reflected sound. In single-barrier situations, this would help to reduce the raspy quality and apparent increase in the sound's duration. The most common absorptive sound barriers contain porous material (see above) which helps to reduce mainly mid- to high-pitched sound reflections. Not all sound-absorbing barrier systems perform equally well.

ABSORPTIVE NOISE BARRIER

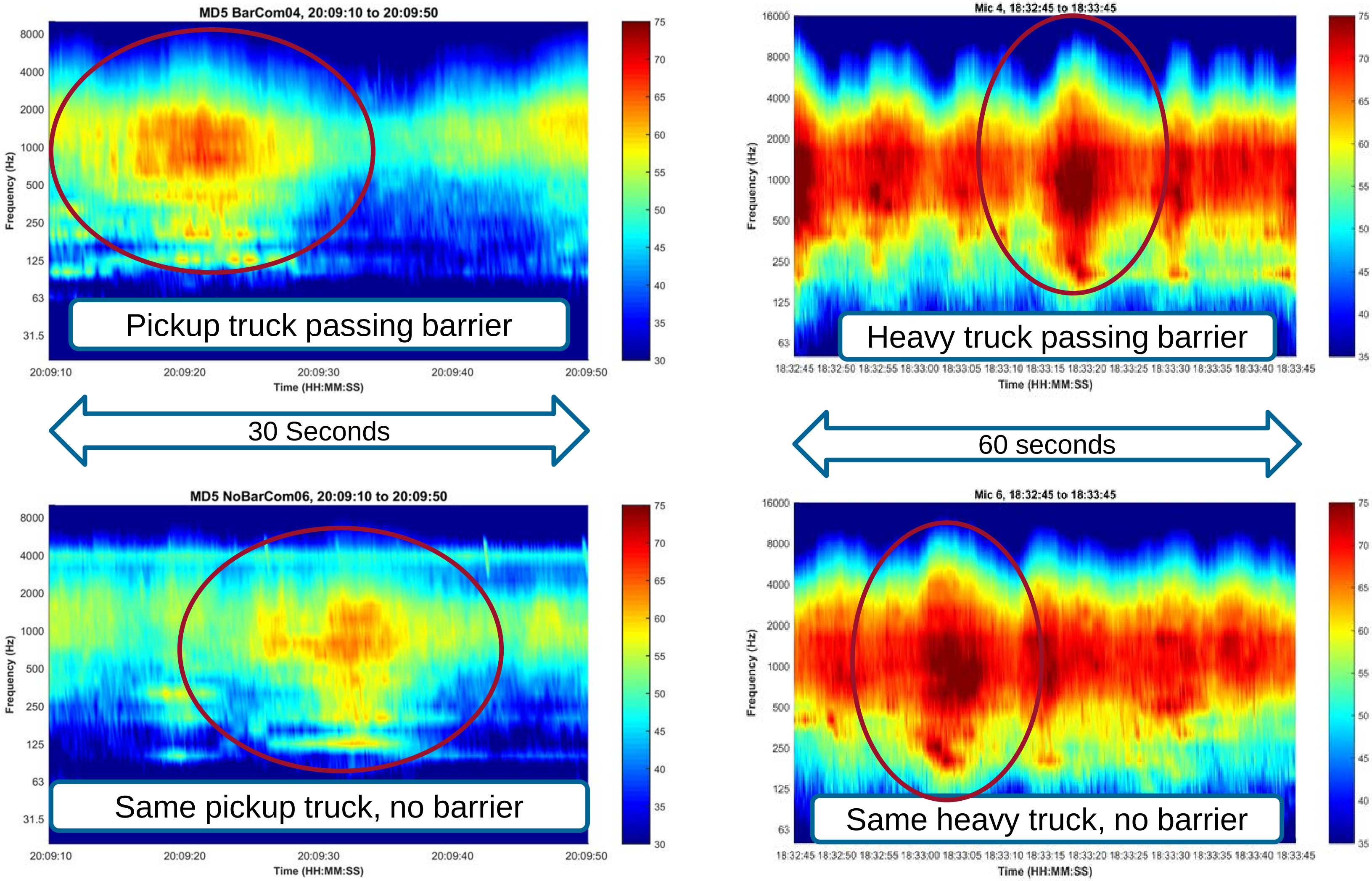
SOUND REFLECTING OFF BARRIER
SOUND TRAVELING DIRECTLY FROM VEHICLE

- Why are barriers not on both sides of the road?
- Want more information?

Spectrogram Analysis

- 3D spectral time histories
- Screened time periods (remove invalid data)
- Identify individual pass-by events
  - Verify vehicle from logs and video
  - Clearly identified at both Barrier and No Barrier sites
- Process audio recordings (48k samples/sec)
  - 1/3-octave bands
  - 1/8-second intervals
- Plot spectrograms and compare mic pairs

Spectrogram Results by Barrier Type



REFLECTIVE

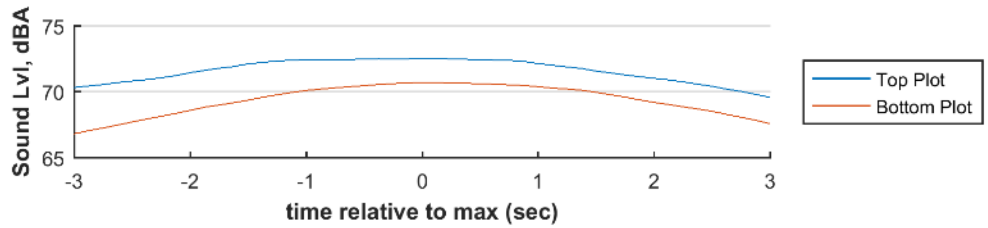
ABSORPTIVE

Difference Spectrograms

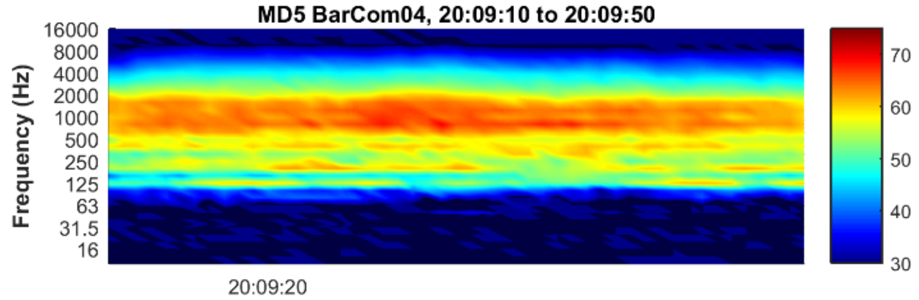
- Developed to identify subtleties and compare reflective to absorptive
- Applied to individual pass-by events
- Extracted spectrum at point in time for pass-by events

Example Process

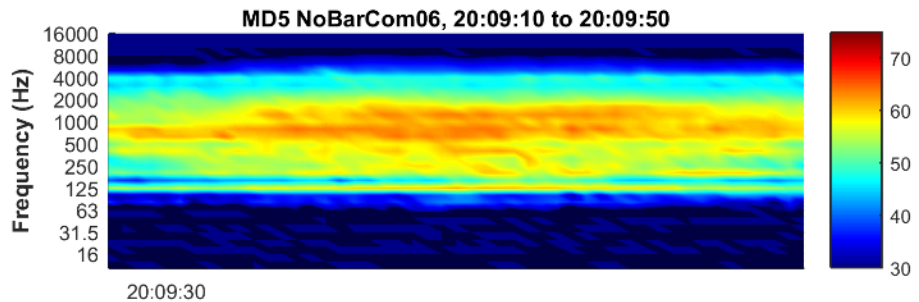
Align maxima



Barrier event spectrogram



No barrier event spectrogram

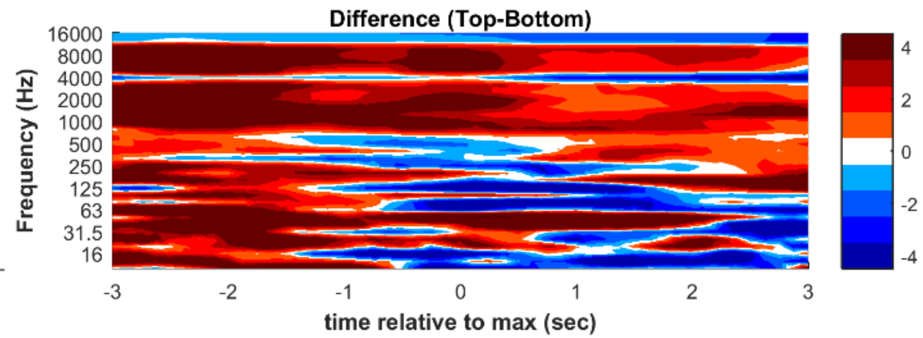


Difference spectrogram

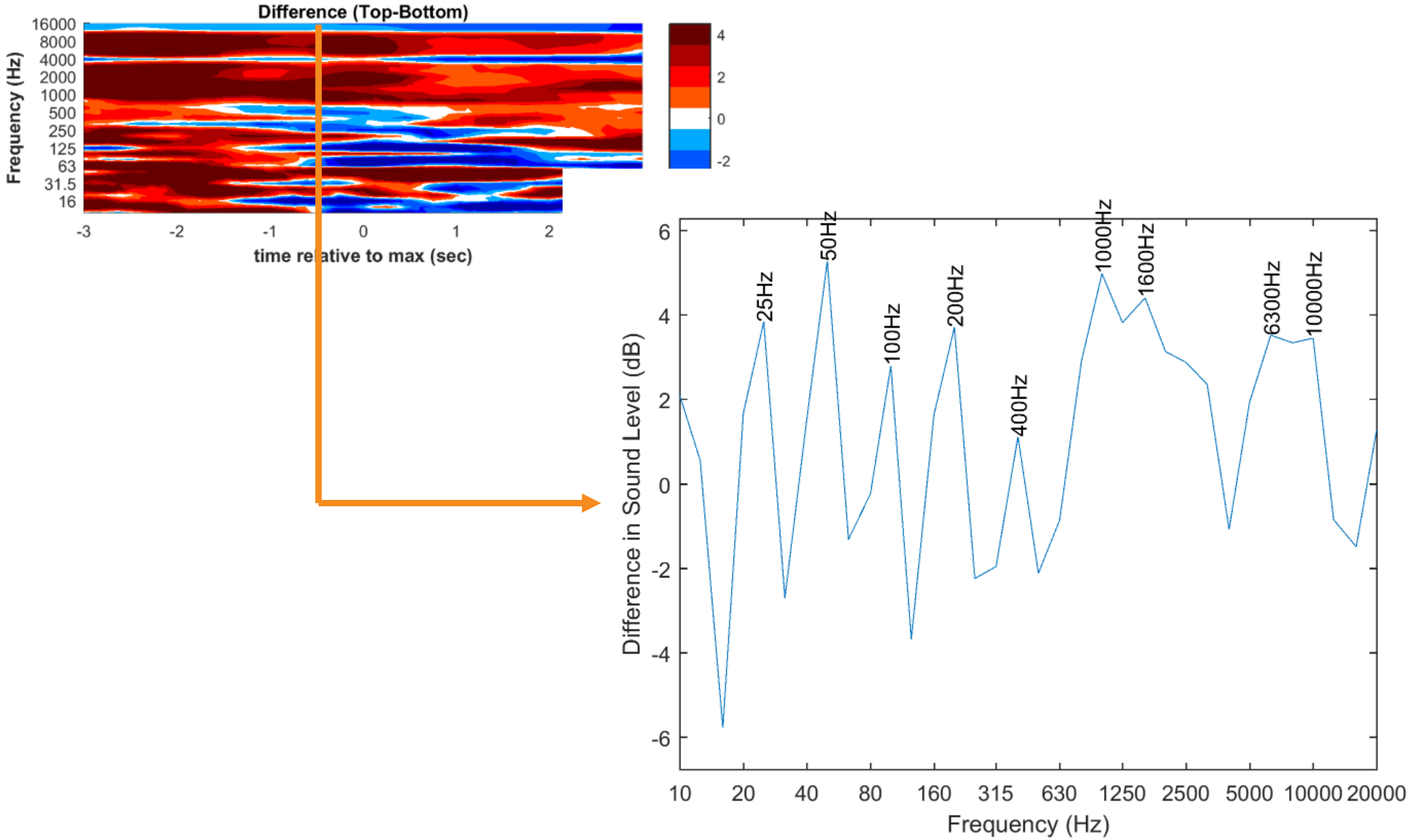
red = barrier louder

white = no difference

blue = no barrier louder



“Hot Lines” Frequencies



Comb Filtering

- Analyzed relationship of peak frequencies
- Direct and reflected wave interference results in harmonically related peaks/dips (constructive/destructive interference)

  → Comb filtering
- Changes sound quality: adds raspiness/buzziness

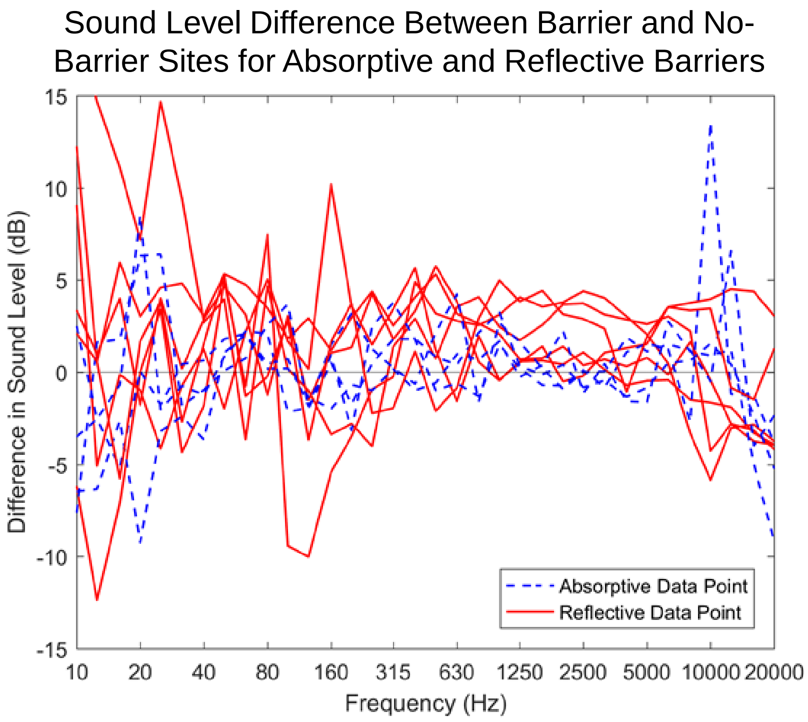
vehicle pass-by

vehicle pass-by, 20 ms delay added

vehicle pass-by, sweep delay added
(20 ms - 100 ms -20 ms)

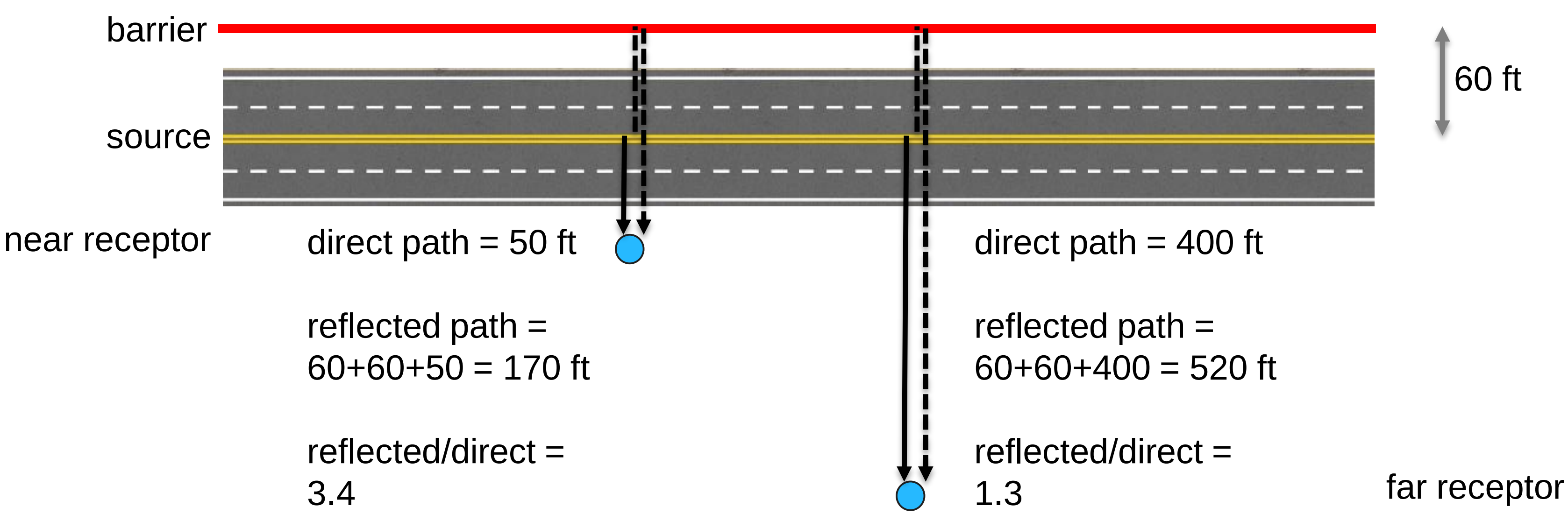
Barrier Type and Comb Filtering

- Reflective barrier peaks
  - Generally more pronounced
  - Show strong harmonic relationship 500 Hz and below
- Absorptive barrier peaks
  - Generally lower amplitude and less prominent harmonic relationship
  - Reduced comb-filtering effect (should confirm with narrow-band analysis)



Barrier Reflections Screening Tool

- Provides a quick estimate of noise increase due to opposite barrier
  - Based strictly on path lengths and cylindrical spreading
  - Smaller ratio of reflected path length / direct path length = greater effect



Barrier Reflections Screening Tool – Input/Output

- "Based on distances"

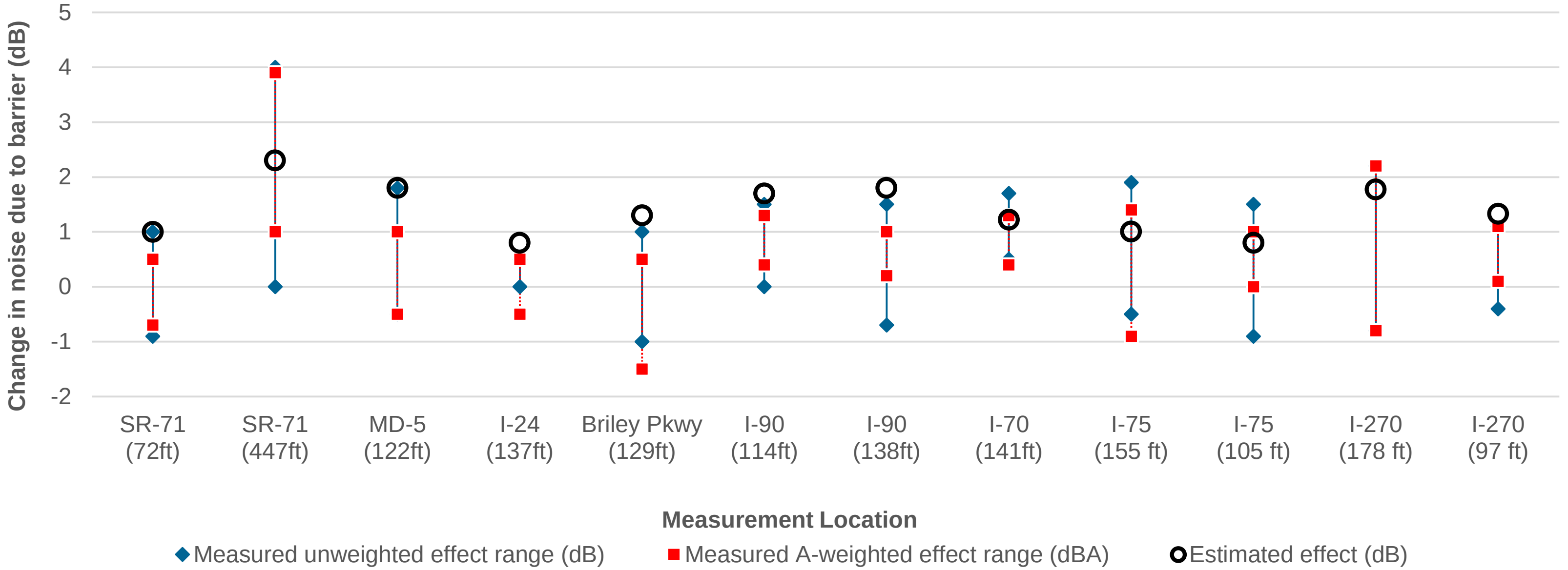
direct path length [ft or m]	70
distance from traffic noise source to barrier [ft or m]	100
source offset (distance up (-) or down (+) road) (optional) [ft or m]	200
direct path shielding amount (optional) [dB]	
barrier reflected path shielding amount (optional) [dB]	
Increase in sound due to reflections [dB]	**2.1**

- "Based on coordinates"

	X (parallel to travel direction)	Y (perpendicular to travel direction)	Z (ground elevation)	Receptor height (above ground)
Source	200	0	0	
Receptor	0	-70	0	5
Barrier		100		
direct path shielding amount (optional) [dB]				
barrier reflected path shielding amount (optional) [dB]				
Increase in sound due to reflections [dB]	**2.1**			

Barrier Reflections Screening Tool – Validation

- Estimated effect falls within/slightly above measured ranges
- Effect dominated by path lengths



Conclusions based on Spectrogram Analysis

- Spectrograms show less indication of reflection effects for absorptive barriers compared to reflective barriers
- Difference spectrograms reveal harmonically related peaks (comb filtering effect)
  - Can be perceived as the sound being raspy or buzzy
  - Absorptive barriers may reduce the effect

Questions?