NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Strategies to Reduce Highway Traffic Noise

March 2, 2023

1:00 – 2:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

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AICP Credit Information

1.5 American Institute of Certified Planners Certification Maintenance Credits

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Log into the American Planning Association website to claim your credits

Contact AICP, not TRB, with questions

Purpose Statement

The most common approach to reducing highway noise traffic is noise barriers, however there are many alternatives state departments of transportation can consider that may be more context- and cost-appropriate. This webinar will examine these alternatives to reducing highway traffic noise. Presenters will provide a flowchart-based model for deciding which strategy is best, along with a handbook to evaluate noise reduction strategies and improve implementation.

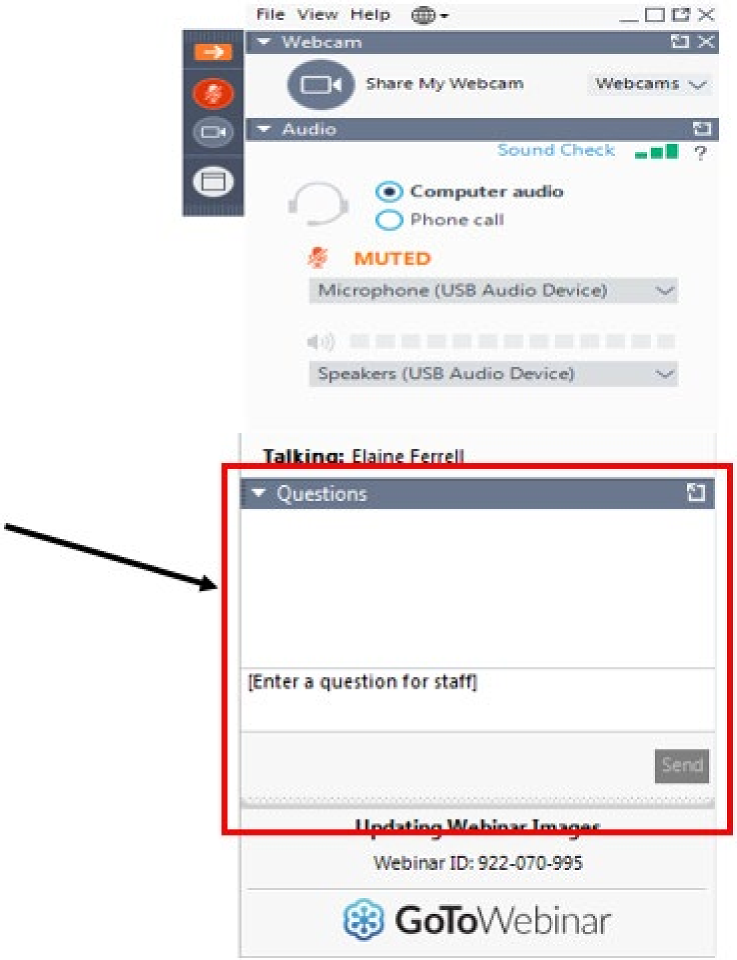
Learning Objectives

At the end of this webinar, you will be able to:

- Identify highway noise reduction strategies other than traditional noise barriers
- Evaluate available strategies for inclusion in highway projects
- Improve implementation of noise-reducing strategies and related highway traffic noise predictions

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters

Judy Rochat
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Cross-Spectrum Acoustics

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ms consultants, inc.

TRB Webinar March 2, 2023:

Strategies to Reduce Highway Traffic Noise

Judy Rochat, Ph.D.
Cross-Spectrum Acoustics

Karel Cubick
ms consultants

Webinar Learning Objectives

1. Identify highway noise reduction strategies other than traditional noise barriers.
2. Apply flowcharts to help evaluate strategies for inclusion in highway projects.
3. Improve implementation of noise-reducing strategies and related highway traffic noise predictions.

Webinar Content Based on NCHRP Project 25-57

- NCHRP Project 25-57, Report 984: *Breaking Barriers: Alternative Approaches to Avoiding and Reducing Highway Traffic Noise Impacts*
- NCHRP staff: Ann M. Hartell and Jarrel McAfee
- Transportation Research Board (TRB) liaison: Christine Gerencher
- Panel
  - Chair Adam Alexander
  - American Association of State Highway Transportation Officials (AASHTO) Monitor Noel Alcala, P.E.
  - Members Patrick Gant, P.E., John Hencken, Mary Dickens Pair, P.E., Kenneth Polcak, and Peter Wasko
- Special mentions
  - 50+ individuals who participated in the literature review survey and interviews and provided documents and data, including those from AASHTO and TRB
  - Dr. Ysbrand Wijnant and Bart Willems from the University of Twente and 4Silence, for providing valuable noise predictions for barrier diffractor tops

NCHRP Project 25-57 Research Team

Cross-Spectrum Acoustics

Judy Rochat, Ph.D., Principal Investigator

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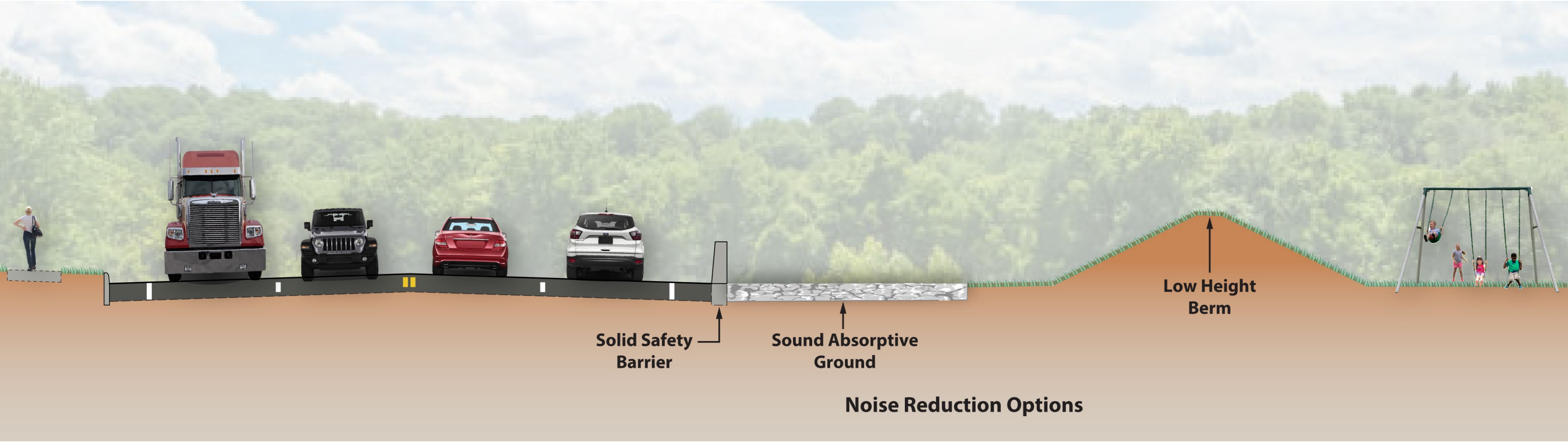

Outline

- Motivation and objectives
- Research approach
- Findings by strategy category
- Application of findings
- Conclusions

Motivation and Objectives

NCHRP 25-57 Motivation

- Highway traffic noise can adversely affect adjacent communities
- Noise barriers are effective but cannot always be constructed in accordance with State policies
- A broader examination of modern noise reduction strategies could allow States to more effectively improve the noise environment

NCHRP 25-57 Objectives

- Key objective: develop a resource detailing innovative approaches beyond the use of noise barriers to avoid and minimize highway traffic noise and address noise complaints
- Resource to provide:
  - Ranges of noise reduction benefits

Decrease	Perception
3 dB	Barely perceptible
5 dB	Readily perceptible
10 dB	Half as loud

  - Cost factors

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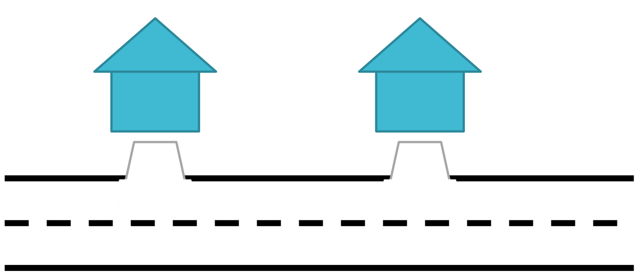
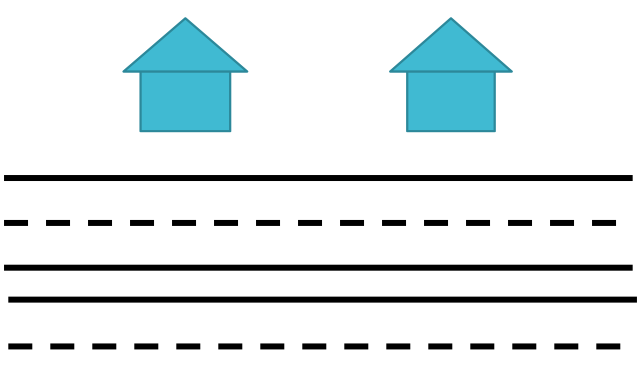
  - Context-appropriateness for design choices and management strategies that may be adopted for other reasons, but that provide noise reduction co-benefits, as well as those adopted specifically to address noise

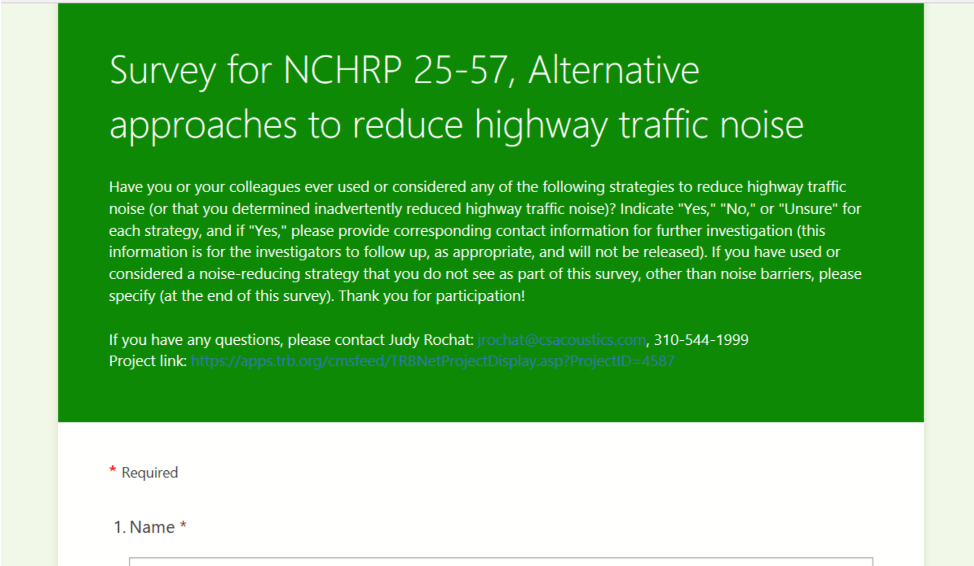




Research Approach

Literature and Data Review

- 14 primary strategies were examined and summarized in terms of noise reductions, cost, and context appropriateness
- Over 170 references were reviewed
  - National and international references
  - Published research and practice reports, papers, and policies
- Examination supplemented by survey with AASHTO and TRB noise professional respondents
  - Provided additional references and information
- Brief TNM analysis completed for for some strategies


Survey for NCHRP 25-57, Alternative approaches to reduce highway traffic noise

Have you or your colleagues ever used or considered any of the following strategies to reduce highway traffic noise (or that you determined inadvertently reduced highway traffic noise)? Indicate "Yes," "No," or "Unsure" for each strategy, and if "Yes," please provide corresponding contact information for further investigation (this information is for the investigators to follow up, as appropriate, and will not be released). If you have used or considered a noise-reducing strategy that you do not see as part of this survey, other than noise barriers, please specify (at the end of this survey). Thank you for participation!

If you have any questions, please contact Judy Rochat: jrochat@csacoustics.com, 310-544-1999
Project link: https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4587

* Required

1. Name *

Noise-Reducing Strategy Category	Strategy
On-road design choices	Quieter bridge decks and joints
	Quieter rumble strip design
	Quieter pavements for travel lanes and/or shoulders
Highway design choices	Horizontal and vertical alignment
	Solid safety barriers in lieu of guardrail
	Separation zones between vehicle travel lanes and side paths for nonmotorized users
Right-of-way design choices	Low berms
	Vegetated screens
	Vegetated swales and retention basins
	Sound-absorbing ground surface and ground treatment adjacent to the highway
	Solar panels
Operations management strategies	Speed or truck restrictions
Implementations by receptors or local governments	Approaches that can be implemented by subdivision developers, homeowner associations, special districts, or local governments
Sound absorptive treatment	Sound absorptive treatment on retaining walls, bridge understructures, or other surfaces

Noise-Reducing Strategy Category	Strategy	
On-road design choices	Quieter bridge decks and joints	
	Quieter rumble strip design	
	Quieter pavements for travel lanes and/or shoulders	
Highway design choices	Horizontal and vertical alignment	
	Solid safety barriers in lieu of guardrail	Supplement with road elevation and diffractor top
	Separation zones between vehicle travel lanes and side paths for nonmotorized users	
Right-of-way design choices	Low berms	Supplement with road depression and soft ground on berm
	Vegetated screens	
	Vegetated swales and retention basins	
	Sound-absorbing ground surface and groun	Supplement with quieter pavement
	Solar panels	
Operations management strategies	Speed or truck restrictions	
Implementations by receptors or local governments	Approaches that can be implemented by subdivision developers, homeowner associations, special districts, or local governments	
Sound absorptive treatment	Sound absorptive treatment on retaining walls, bridge understructures, or other surfaces	

Selected for further investigation

Further Investigations

- Used FHWA Traffic Noise Model (TNM) v3.0 to predict noise reduction with varying parameters
- 8 roadway base cases
  - 2- and 4-lane narrow and wide streets
  - 4- and 8-lane narrow and wide freeways/highway
- Default ground acoustically hard (hard soil) and soft (lawn)
- 0, 5, and 15% heavy trucks
- Receivers
  - Distances every 25 ft, out to 1000 ft (from center of near travel lane)
  - Heights 5 and 15 ft

Findings

On-Road Design Choices

- Quieter bridge decks and joints
- Quieter rumble strip design
- Quieter pavements for travel lanes and/or shoulders

On-road design choices – quieter bridges, rumble strips, and pavements

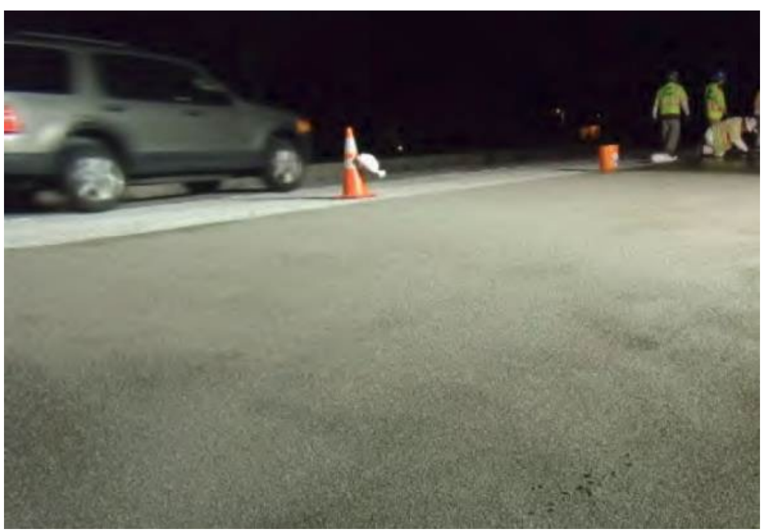
Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Quieter bridge decks	5-10 dB compared to conventional bridge decks (near source)	$$-$$$	Bridges or other structures
Quieter bridge joints	6-9 dB compared to conventional bridge joints (near source)	$$$-$$$$	Bridges or other structures with expansion joints, particularly designed seismic activity
Quieter rumble strips	3-7 dB compared to conventional rumble strips (near source)	$-$$$	Outside edges of travel lanes or centerline of undivided roadway
Quieter pavements	Up to 7 dB reduction for diamond grinding Up to 9 dB reduction for open-graded/rubberized Up to 6 dB reduction for thin bonded asphalt	$$-$$$$	All pavement surfaces

Quieter bridge decks

Noise Benefit
5-10 dB compared to conventional bridge decks (near source)

- Quieter applications
    - Polyester overlay
    - Diamond grinding

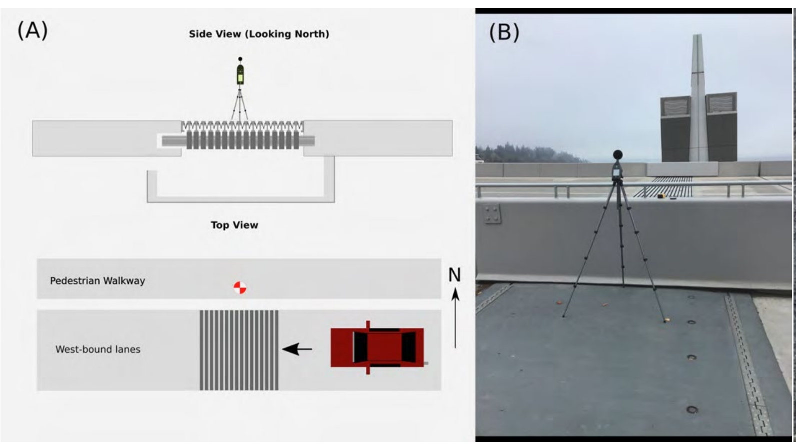
    - Reduce texture depth
    - Improve texture uniformity
    - Create “negative” texture that reduces tire tread block vibrations
    - Result is reduced tire-pavement noise



Quieter bridge joints

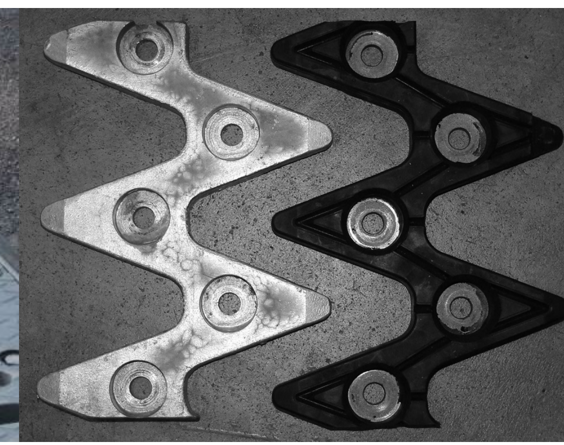
Noise Benefit
6-9 dB compared to conventional bridge joints (near source)

- Quieter applications
  - Patterned joint cover plates; examples: finger joints, sinusoidal shapes
  - Eliminate undesirable "zipper" sound commonly associated with large expansion joints



Washington DOT (2019)

Example: TENSA® FINGER cantilever



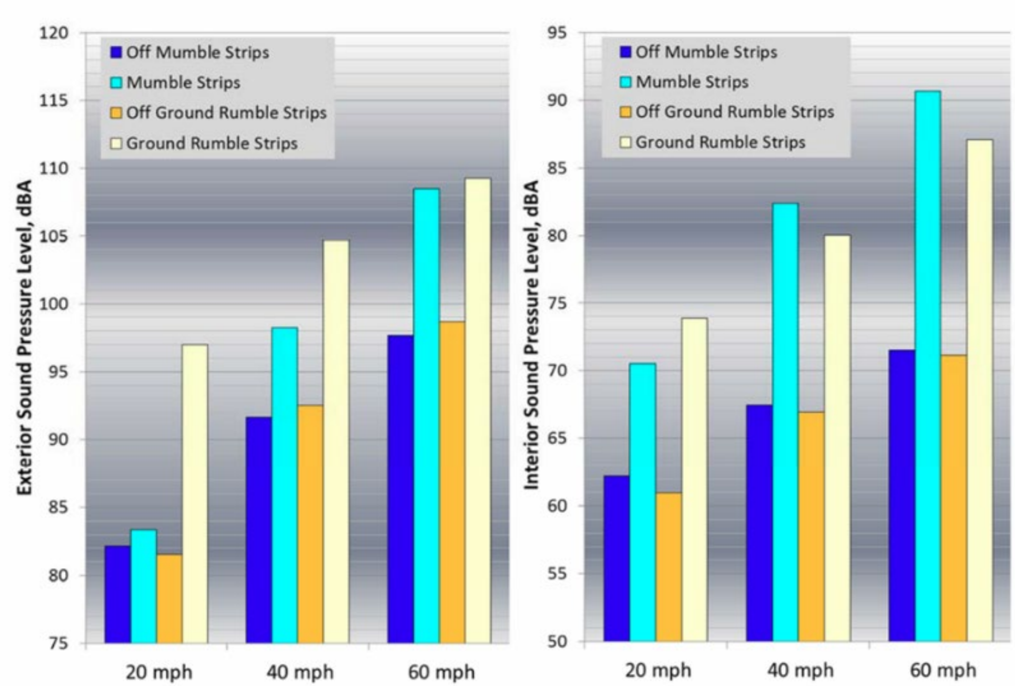
Glaesser, et al., NCEJ, Vol. 60, No. 2 (2012)

Quieter rumble strips

Noise Benefit
3-7 dB compared to conventional rumble strips (near source)

- Quieter rumble strips
  - Unique patterns to reduce impact energy
  - Rumble "wave" using a sinusoid pattern, optimized for occupant safety while reducing exterior noise level
  - Can be installed using conventional equipment with minor modifications

Minnesota DOT (2015)



Caltrans (2012, 2018)

Quieter pavement

Noise Benefit

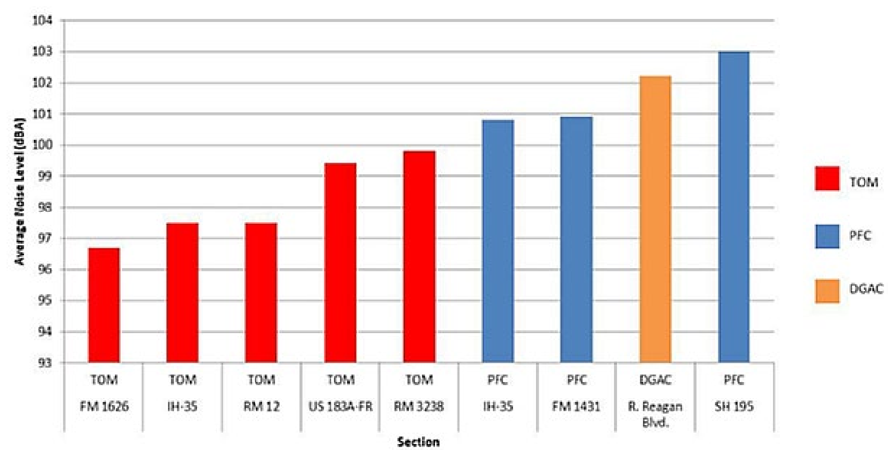
Up to 7 dB reduction for diamond grinding

Up to 9 dB reduction for open-graded/rubberized

Up to 6 dB reduction for thin bonded asphalt

- Quieter pavement
  - Diamond grinding
  - Open-graded or rubberized asphalt
  - Thin bonded asphalt layers

  - Reduce texture depth
  - Improve texture uniformity
  - Create “negative” texture that reduces tire tread block vibrations
  - For some alternatives, increase acoustical absorption
  - Additional benefit from absorptive treatments of pavements on shoulders



Highway Design Choices

- Horizontal and vertical alignment
- Solid safety barriers in lieu of guardrail
- Separation zones

Horizontal and vertical alignment

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Horizontal alignment shift	< 1 dB to 10+ dB depending on extent of shift, site topography, and vehicle types	$$$$-$$$$$	Highways or local roadways with vacant land opposite the sensitive sites
Vertical alignment shift	< 1 dB to 10+ dB depending on extent of shift, site topography, and vehicle types	$$$$-$$$$$	Highways or local roadways where right-of-way is sufficient

Acceptable abatement measures per 23 CFR 772.15

Horizontal alignment shift

Noise Benefit

< 1 dB to 10+ dB depending on extent of shift, site topography, and vehicle types

- Moving the roadway away from noise sensitive sites
- Very expensive and frequently discounted
- Concept overlaps with analysis of alternative alignments intended to avoid utility conflicts, reduce construction cost, or minimize right-of-way impacts
- TNM v2.5 evaluation for arterial street project with minor impacts
  - Roadway shifted 15.2 m (50 ft) away from 1st row receivers: no noise impact (about 2 dB reduction)
  - ROW and construction cost for shifting 533 m (1,750 ft) of roadway 15.2 m (50 ft) laterally exceeds $2,350,000

Vertical alignment shift

Noise Benefit
< 1 dB to 10+ dB depending on extent of shift, site topography, and vehicle types

- Raising or lowering the roadway relative to the noise sensitive site
- May be less expensive than horizontal shift, but still frequently discounted
- 1997 Texas report showed that depressed freeway sections provide the greatest reduction in noise

- TNM v2.5 evaluation for arterial street project with minor impacts
  - Roadway lowered 0.6 m (2 ft) = no noise impact (2 dB reduction)
  - Excavation cost for 457 linear m (1,500 linear ft) of roadway was $101,655
  - No additional right-of-way required for this project
  - Sight distance, drive adjustments, drainage, utility conflicts, not evaluated

Solid safety barriers in lieu of guardrail

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Solid safety barrier in lieu of guardrail freeway	Preliminary: 0.4 dB to 2.6 dB depending on distance to receiver and site topography Further investigations: at 100 ft, 5-7 dB reduction, up to 8 dB with road slightly elevated (assumes tall freeway/highway safety barrier, 6.8 ft)	$$	Limited-access highways if state standards allow
Solid safety barrier in lieu of guardrail arterial	Preliminary: 2.0 dB to 6.6 dB depending on distance to receiver and site topography Further investigations: at 100 ft, 3-4 dB reduction, up to 6 dB with road slightly elevated (assumes tall street/arterial safety barrier, 4.8 ft)	$$	State or local roadways if state or local standards allow

Solid safety barriers in lieu of guardrail

- A safety barrier (guardrail or concrete barrier) shields motorists from structures/steep slopes
  - Considerations for installation of solid safety barrier: the need to maintain access to adjacent properties, the potential for it to be considered a roadside crash hazard

- Further investigations

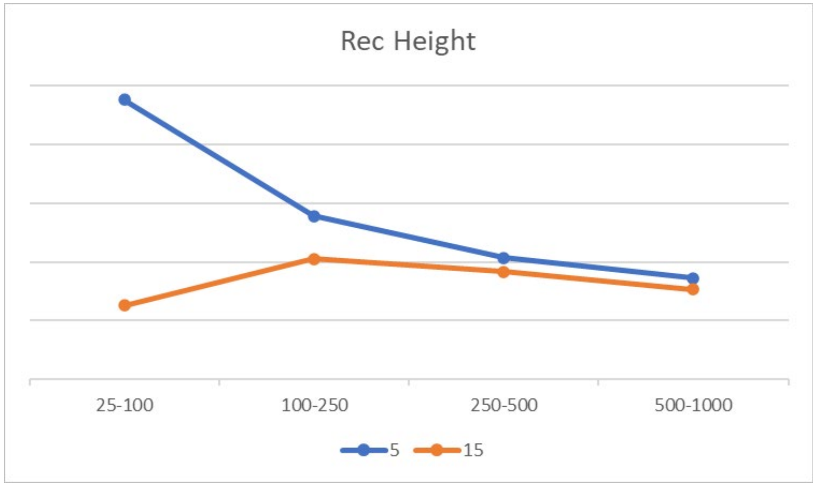
Parameter	Values/descriptions
Safety barrier height	3.5 ft and 4.8 ft for city streets; 4.8 ft and 6.8 ft for freeways
Roadway elevation	At grade and elevated 1, 2, and 3-ft
Diffractor	Safety barrier with and without diffractor

Solid safety barriers in lieu of guardrail

- Noise reduction for same height barrier generally greater for streets
  - Freeways allow for taller safety barrier, however, so can achieve greater reduction
- Noise reduction – further investigations
  - Best for: tallest barriers (4.8 ft for streets, 6.8 ft for freeways), narrow roadways, hard ground sites (e.g., pavement, packed dirt), lower % heavy trucks
  - Enhanced with small road elevation (+1-2 dB)
  - Receiver height/distance dependent

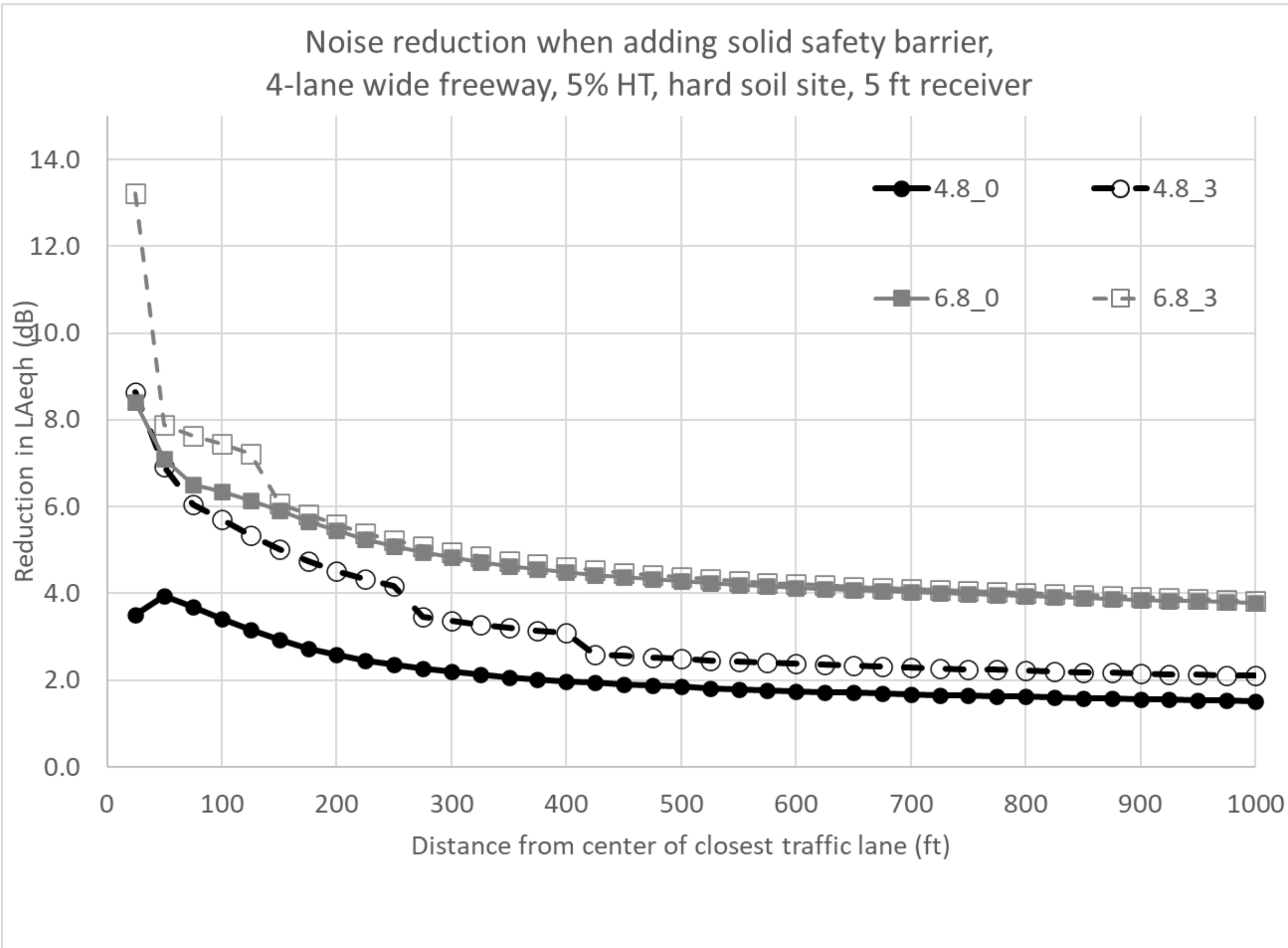
Noise Benefit
Freeway Preliminary: 0.4 dB to 2.6 dB depending on distance to receiver and site topography Further investigations: at 100 ft, 5-7 dB reduction, up to 8 dB with road slightly elevated (assumes tall freeway/highway safety barrier, 6.8 ft)
Street Preliminary: 2.0 dB to 6.6 dB depending on distance to receiver and site topography Further investigations: at 100 ft, 3-4 dB reduction, up to 6 dB with road slightly elevated (assumes tall street/arterial safety barrier, 4.8 ft)

Reduction as a function of distance (ft)



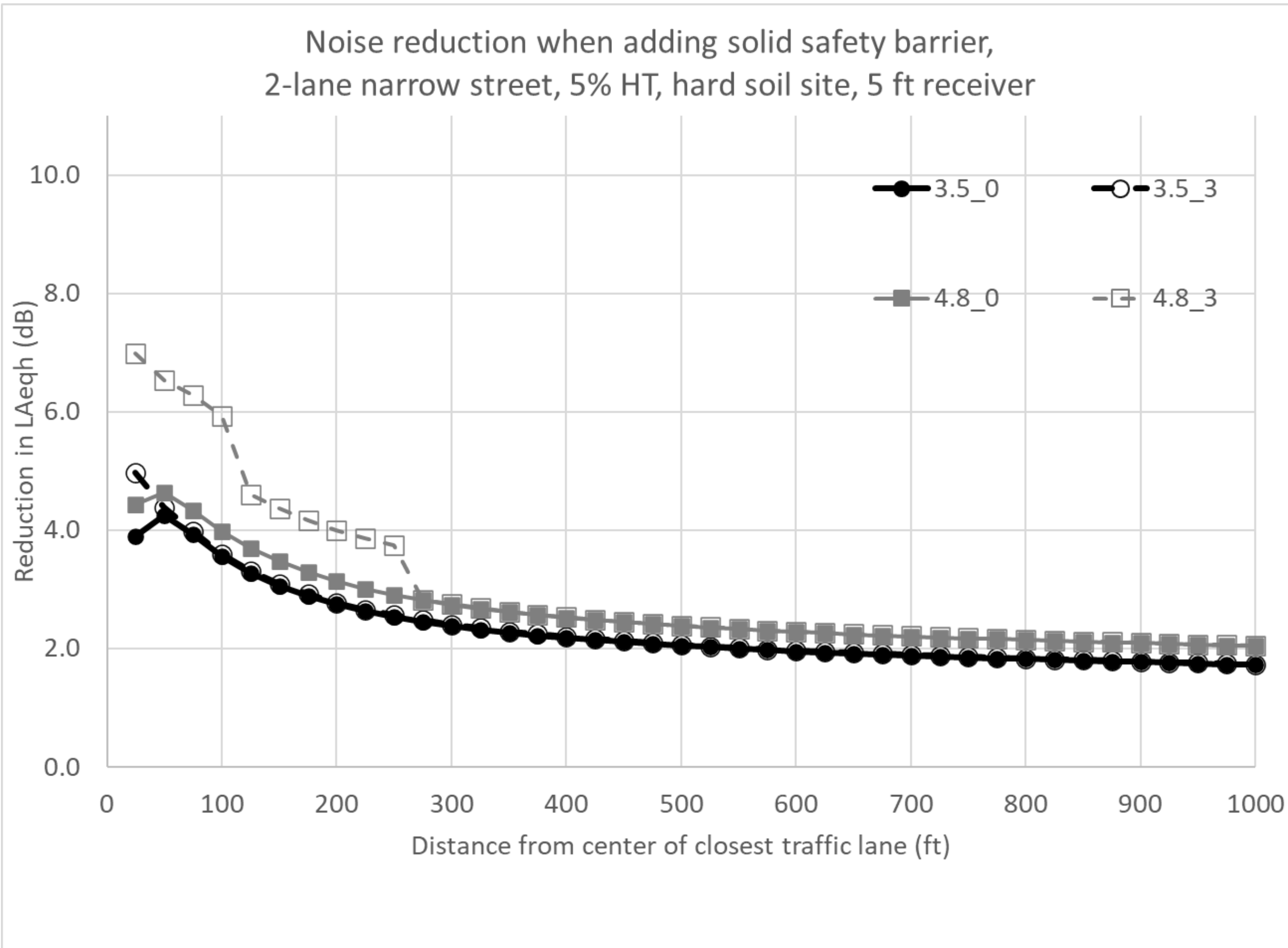
Solid safety barrier – freeway/highway

- Example with 4.8 and 6.8 ft barriers, at grade and road elevated 3 ft



Solid safety barrier – street/arterial

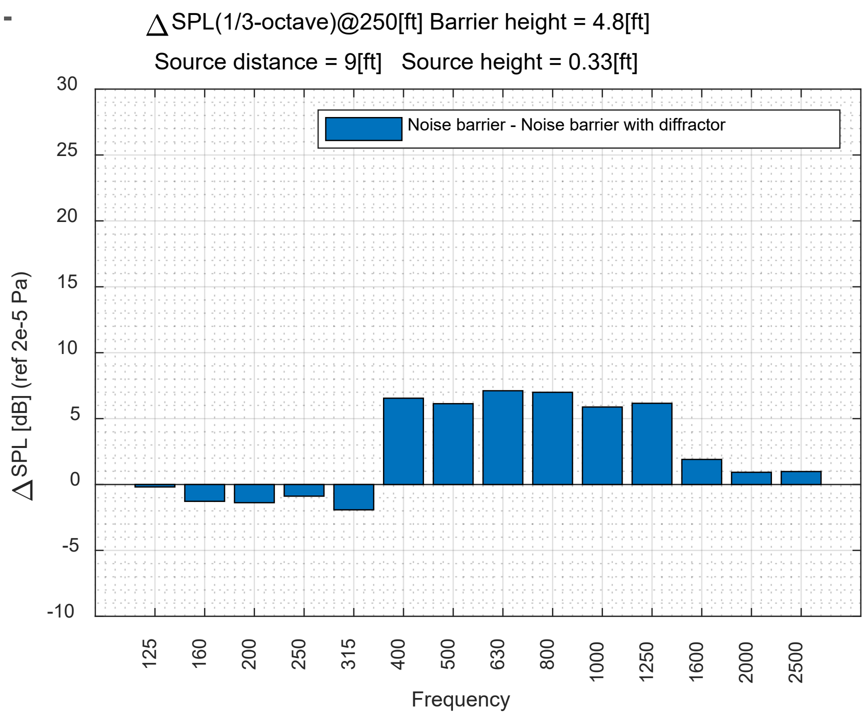
- Example with 3.5 and 4.8 ft barriers, at grade and road elevated 3 ft



Solid safety barrier – diffractor top

- Diffractor top enhances noise reduction
  - Estimated 3 dB broadband increase
    (noise reduction increase = decrease in sound level)
- Substantial reduction at frequencies important to highway traffic noise, 500-1600 Hz
  - Could be tuned for lower frequencies
- Must be tested for safety in the U.S.

©4Silence, WHIStop diffractor



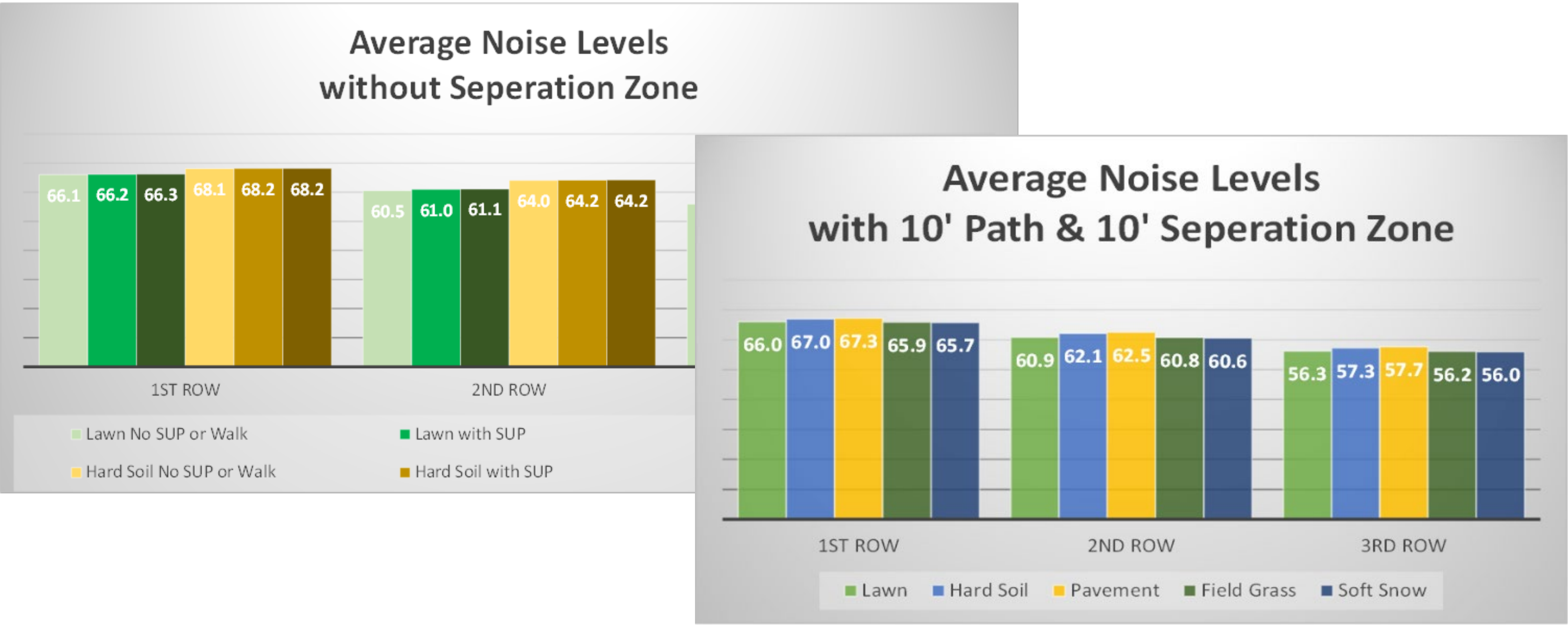
Separation zones between vehicle travel lanes and side paths for non-motorized vehicles

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Separation zone between roadway and side path in TNM (different from default ground type)	Up to 0.3 dB minimal noise reduction	$	Roadways with sidewalks or shared-use paths
Separation zone between roadway and side path in TNM (similar to default ground type)	0.1 dB or 0.2 dB only a slight difference.	$	Roadways with sidewalks or shared-use paths

- separation zones between travel lanes and sidewalks, bike trails, shared-use paths has not been frequently considered
- increase model accuracy 1.2 dB to 1.6 dB if separation zone different from default ground type (hard soil or pavement compared to lawn)

Separation zones between vehicle travel lanes and side paths for non-motorized vehicles

- TNM v2.5 evaluation for a previously completed project
- Added a sidewalk or shared-use path and separations zones
- Very little noise reduction regardless of separation zone ground type



Right-of-Way Design Choices

- Low-height noise berms
- Vegetated screens
- Vegetated swales and retention basins
- Sound-absorbing ground surfaces and ground treatments
- Solar panels

Low-height noise berms

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Standard low-height berms (up to 1.8 m or 6 ft)	2-10 dB (greatest when receivers below road elevation) Further investigations: at 100 ft, 4-7 dB reduction for a 6 ft berm, up to 9 dB with road slightly depressed	$-$$$	Space in ROW
Engineered low-height berms with steeper slopes	Could increase noise reduction by moving peak closer to road Unusually shaped provide no additional benefit	$$-$$$$	Space in ROW (requires less than standard berm)
Low-height berms with absorptive ground	Could increase reduction by up to 5 dB	Geo-graphically dependent	Space in ROW, likely requires maintenance

Low-height berms

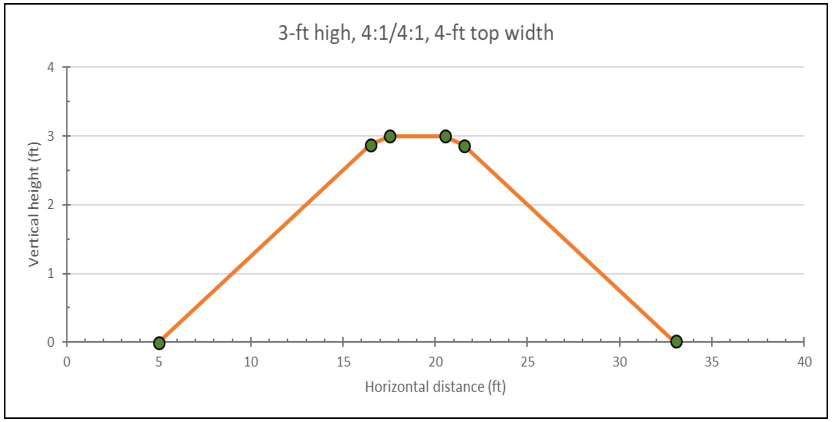
- Noise barriers constructed from natural earthen materials in an unsupported condition
  - Can be low-cost (using surplus materials) and low-maintenance

- Further investigations

Parameter	Values/descriptions
Berm height	3, 4.5, and 6 ft
Berm shape	Slopes 2:1 and 4:1; Slopes 2:1 and 4:1 mixed with 6:1 on traffic side; and Slopes 2:1 and 4:1 mixed with retaining wall on traffic side
Berm top width	2 ft and 4 ft
Berm placement	In ROW and considering berm footprints: "near" (close to road) and "far" (at ROW line)
Roadway depression	At grade and depressed 1, 2, and 3 ft

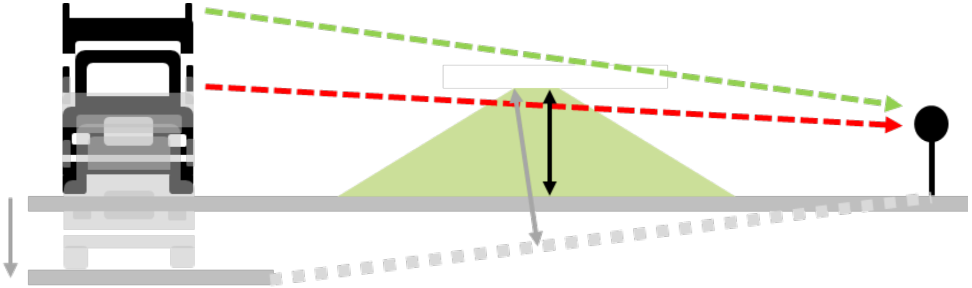
Other parameters

Modeled berm with rounded edges following FHWA guidance



Depressed the road to achieve additional noise reduction

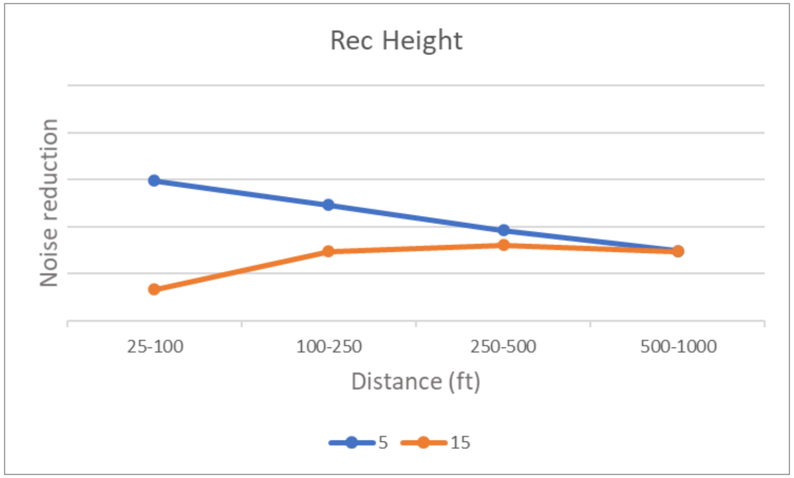
- 1, 2, 3 feet
- Increases effective height of berm



Standard low-height berms

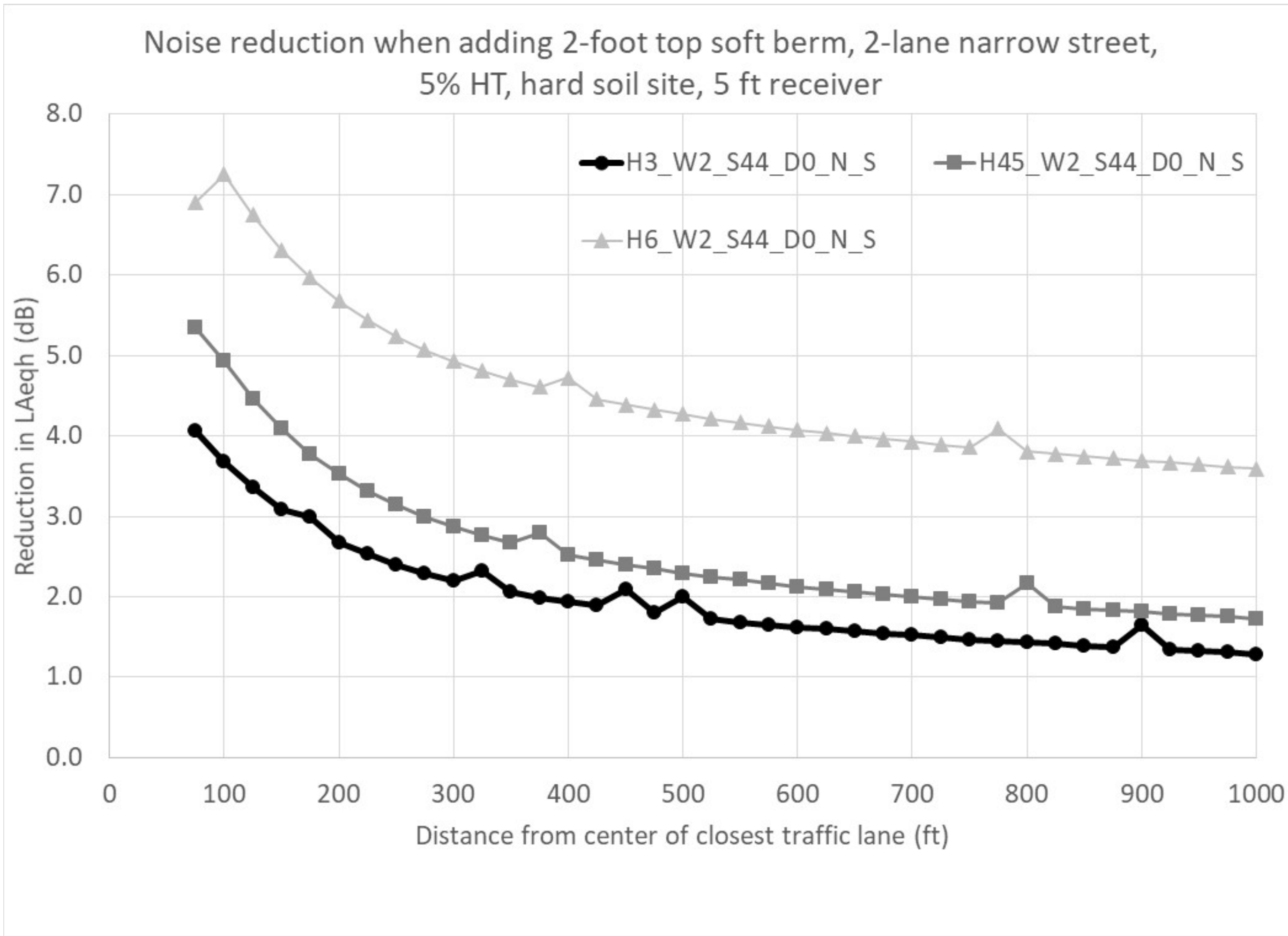
Noise Benefit
2-10 dB (greatest when receivers below road elevation) Further investigations: at 100 ft, 4-7 dB reduction for a 6 ft berm, up to 9 dB with road slightly depressed

- Noise reduction – further investigations
  - Best for: tallest berm (6 ft), narrow roadways, hard ground sites (e.g., pavement, packed dirt), lower % heavy trucks
  - Enhanced with small road depression (+2 dB); also with absorptive surface if site is generally hard ground (+2 dB)
  - Berm shape (slope, top width, engineered with retaining wall to move closer to traffic: up to 2 dB influence)
  - Receiver height/distance dependent



Low-height berms – noise reduction over distance

- Example with berm heights 3, 4.5, and 6 ft, 4:1 slope, 2 ft top width, soft berm, at grade



Vegetated screens

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Wide vegetation belts (> 20 m or 65 ft)	Measured 3-9 dB; up to 10 dB predicted with optimized planting	$-$$$	Space in ROW; areas that can support vegetation
Moderate-to-low thickness vegetation (< 20 m or 65 ft)	Measured 1-3 dB; up to 6 dB predicted with optimized planting	$-$$	Space in ROW; areas that need minor noise reduction and can support vegetation
Vegetation to improve adverse sound propagation effects	Reduce negative downwind effects; reduce likelihood of temperature inversion	$$	Sites with a wall noise barrier; sites that can support vegetation
Vegetation to improve perception	None, but subjective reports of decrease in annoyance	$	Areas that do not qualify for noise abatement, but report traffic noise annoyance

Vegetated screens

Noise Benefit
Wide belts (> 20 m or 65 ft): measured 3-9 dB; up to 10 dB predicted with optimized planting Low-to-moderate thickness (< 20 m or 65 ft): measured 1-3 dB; up to 6 dB predicted with optimized planting

- Optimized planting
  - Tree-spacing as close as possible (< 3 m or 10 ft)
  - Pseudo-random spacing
  - Tree stem diameter > 0.11 m (4 in)
  - Height of tree canopy affects reduction (too high and sound goes under)
  - Canopy shape affects reduction
    - Triangular may be ideal behind barriers to reduce adverse downwind effects
    - Start of canopy below, at, or above the top of wall affects distance where reduction is seen
- Undergrowth important to noise reduction
  - Wide belts with trees too dense may limit growth
- Shrubs may be effective with low source and receiver heights
- Vegetation may have a calming effect and reduce annoyance

Vegetated swales and retention basins

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Vegetated bio-filter basin	< 1 dB for multi-lane highway 1-2 dB for 2-lane road (most reduction farther from road, > 91 m or 300 ft)	$	Highways/roads where swale/basin is needed

- Constructed to reduce or store storm water run-off
- A vegetated biofilter consists of a grassed portion of the graded shoulder, grassed foreslope, and flat grassed ditch

Sound-absorbing ground surfaces and ground treatments adjacent to a highway

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Acoustically soft ground	1-3 dB for traditional soft surfaces Up to 12 dB for highly absorptive surfaces, most reduction with placement close to source (narrow shoulder) and extending over half the distance to receiver Further investigations: at 100 ft, 4-5 dB reduction, up to 6 dB combined with quieter pavement	$-$$$	Space in median and ROW
In-ground treatments	2-8 dB, most reduction for wider strip, lattice structure	$$$	ROWs that can accommodate embedded structures close to travel lane (likely 2-lane road)
Above-ground treatments	3-11 dB, most reduction for wider strip, lattice structure	$$-$$$$	ROWs that can accommodate above-ground low structures close to travel lane (likely 2-lane road)

Acoustically soft ground

- Soft ground examples: gravel (highly absorptive), forest floor, grass


Gravel


Shredded rubber mat


Forest floor


Sand


Field grass

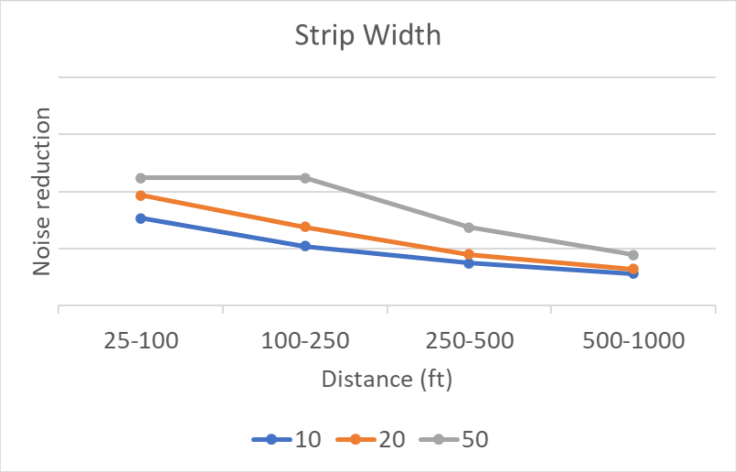
- Further investigations

Parameter	Values/descriptions
Absorptive strip placement	Edge of shoulder with strip widths of 10, 20, and 50 ft
Absorption value	5,000; 10; and 1 cgs rayls [representing hard soil (for default ROW and for comparison to softer surfaces), gravel, and very highly absorptive gravel, respectively]
Roadway pavement	TNM Average and OGAC

Acoustically soft ground

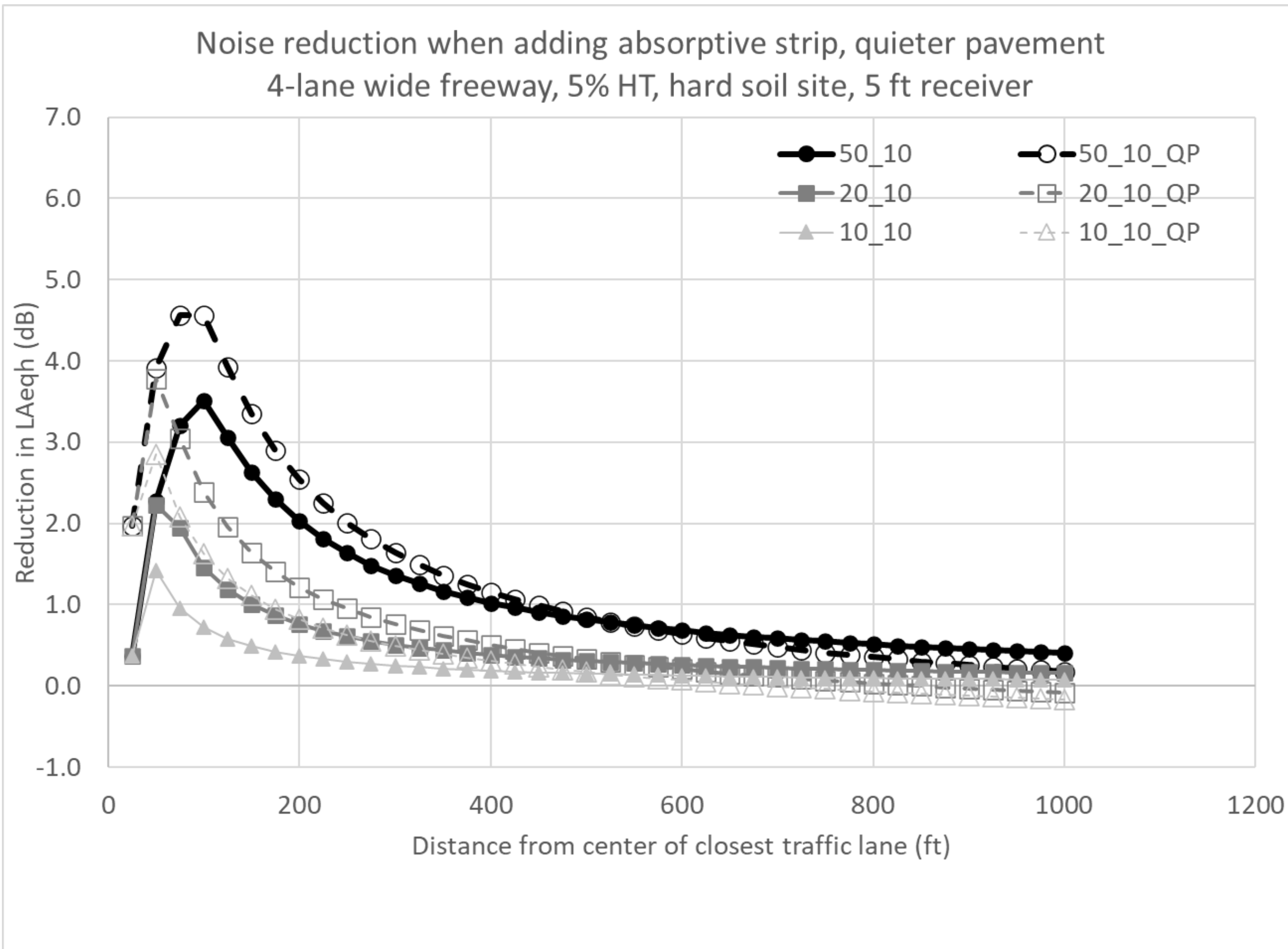
Noise Benefit
1-3 dB for traditional soft surfaces Up to 12 dB for highly absorptive surfaces, most reduction with placement close to source (narrow shoulder) and extending over half the distance to receiver Further investigations: at 100 ft, 4-5 dB reduction, up to 6 dB combined with quieter pavement

- Noise reduction – further investigations
  - Best for: widest strip (50 ft), narrow roadways, hard ground sites (e.g., pavement, packed dirt), lower % heavy trucks
  - Enhanced with quieter pavement (+1-2 dB for TNM OGAC, more for quieter pavements)
  - Effects at acoustically soft ground sites < 1 dB
  - Differences between highly absorptive gravel (EFR 10 cgs rayls) and very highly absorptive gravel (EFR 1 cgs rayls) is negligible
  - Effect of strip widths is distance dependent



Acoustically soft ground

- Example with strip widths 10, 20, and 50 ft; EFR 10 cgs rayls; with and without quieter pavement



Acoustically soft ground (ASG) – targeted investigations

- ASG and quieter pavement (QP) complementary noise reduction
  - At lower frequencies, reduction is controlled by ASG
  - At mid to higher frequencies, reduction is controlled by ASG and QP

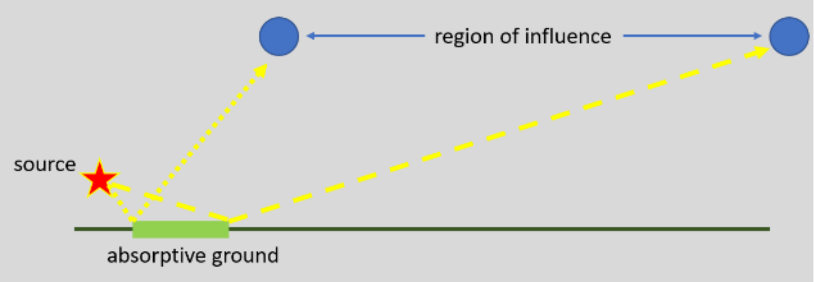
- Region of influence (ROI)

Wider strip = wider ROI

Higher noise source = ROI closer to road

Higher receiver = ROI farther from road

Road lane closer to strip = ROI closer to road



(cross section)

In-ground treatments

Noise Benefit
2-8 dB, most reduction for wider strip, lattice structure

- Grooves or pits add ground roughness to help reduce sound
- Structure types
  - Multiple parallel walls
  - Lattice structure
  - Resonators (can be tuned to reduce specific frequency, although only 2-3 dB reduction embedded in shoulder)
- Structure parameters investigated (walls, lattice)
  - 0.2-0.3 m (0.7-1 ft) deep
  - 1-24 m (3-79 ft) wide
  - 2.5 m (8 ft) from nearest source

©4Silence, WHISstone lattice structure

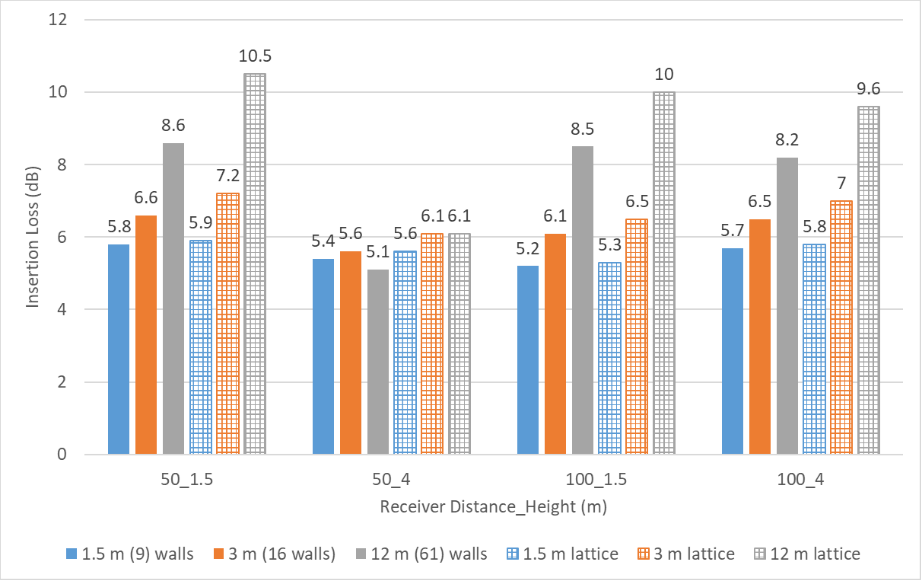
- Less effective than raised structure, but may be preferred
  - May be above ground construction restrictions
  - Might be combined usefully with drainage arrangements

Above-ground treatments

Noise Benefit

3-11 dB, most reduction for wider strip, lattice structure

- Adds ground roughness to scatter and help reduce sound
- Structure types
  - Multiple parallel walls
  - Lattice structure
- Structure parameters investigated
  - 0.25-0.3 m (0.8-1 ft) height
  - 2-12 m (7-39 ft) wide
  - 2.5 m (8 ft) from nearest source



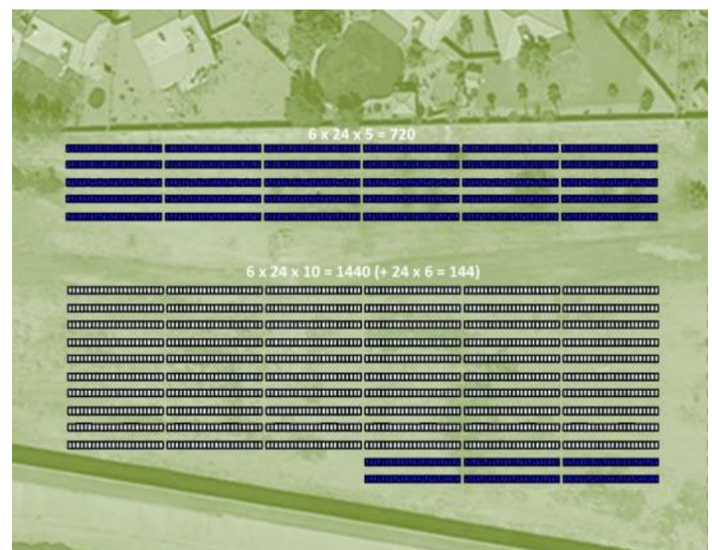
Data source: Attenborough (2016)

- Reduction depends on height, spacing, width, cross-sectional shape
  - Lattice configurations ½ width of parallel walls have comparable reduction
  - Effectiveness not affected by receiver height or distance
  - Gaps between walls/cells can be filled up to 30% by gravel, sand, soil, plants

Solar panels

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Solar panels	If continuous panels assumed, then > 11 dB, however gaps between arrays and panel angles need to be considered	($$-$$$$) Cost for purchase, installation, and maintenance of panels	Highways with ROW space

- Most effective:
  - Multi-row array
  - Minimal gaps horizontally and vertically



Arizona DOT (2019)

Operations Management Strategies

Speed restrictions

Truck restrictions

Speed and truck restrictions

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Speed restrictions	~2 dB with a mixed traffic reduction in speed of 16 km/h (10 mph)	$-$$	Limited-access highways or local road networks
Truck restrictions	10 dB or more, vehicle max pass-by levels 1-6 dB overall noise (L_{Aeq})	$-$$	Most commonly implemented on local road networks; may be used on limited access roads

Speed restrictions

Noise Benefit
~2 dB with a mixed traffic reduction in speed of 16 km/h (10 mph)

- Based on TNM: for combined traffic, expect a 2 dB reduction (L_{Aeq}) for a 16 km/h (10 mph) reduction in speed
- Danish Road Institute, 10% heavy trucks

Speed Reduction	Noise Benefit Leq (dBA)
110 to 100 km/h (68 to 62 mph)	0.7
100 to 90 km/h (62 to 56 mph)	0.7
90 to 80 km/h (56 to 50 mph)	1.3
80 to 70 km/h (50 to 43 mph)	1.7
70 to 60 km/h (43 to 37 mph)	1.8
60 to 50 km/h (37 to 31 mph)	2.1
50 to 40 km/h (31 to 25 mph)	1.4
40 to 30 km/h (25 to 19 mph)	0.0

Truck restrictions

Noise Benefit
10 dB or more, vehicle max pass-by levels
1-6 dB overall noise (L_{Aeq})

- TNM emission level differences between heavy trucks (HTs) and automobiles
  - HTs about 9-10 dB higher for highway speeds
  - HTs about 11-14 dB higher for local road speeds
  - Removing HTs reduces pass-by noise substantially
- TNM traffic noise predictions with 10% HTs removed
  - Reduces highway noise about 3 dB
  - Reduces local road noise about 6 dB
- Possible to apply to nighttime only to reduce sleep disturbance (may affect daytime traffic, though)

Sound Absorptive Treatment on Structures

- Retaining walls
- Understructure of bridges
- Tunnels
- Other applications

Sound absorptive treatment on structures

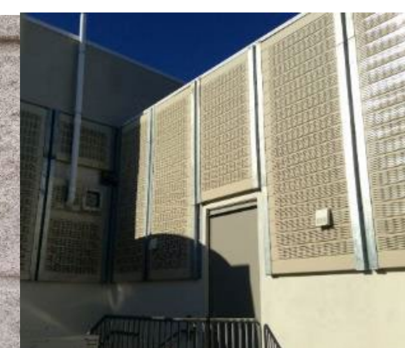
Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Treatment on retaining walls	1-2 dB for opposite side reflections Predicted up to 2.5 for parallel barriers and up to 4 dB for truck/barrier reflections	$-$$$	Where retaining walls can reflect noise to sensitive receptors
Treatment on bridge understructures	Measured up to 6 dB for highway and 11 dB in lab Predicted up to 4 dB for sound absorptive treatment	$$-$$$$	Elevated highway bridge structures or those over depressed highways where reflections can affect sensitive receptors
Treatment in tunnels	Measured 5-10 dB for sound absorptive treatment Predicted 4 dB for surface roughening	$$-$$$$	Highway tunnels where reflections can affect sensitive receptors
Other structure applications	Engineered products: Helmholtz resonators or metamaterials – can be tuned to optimize traffic noise reduction Considerations: curvature of a wall – avoid focusing sound; application to safety barriers Green wall systems on walls and rooftops can reduce reflections	--	Locations where structure surfaces can reflect noise

Reflections and absorptive treatment

- Reflections of sound at a structure interface can increase noise at a receptor
  - Substantial increase if direct noise is shielded
- Sound absorptive treatment
  - Can benefit receptors on one or both sides of a roadway
  - Reduces magnitude of sound energy: as sound travels through the material, the sound waves change direction and follow a longer path, decreasing the energy
  - Example sound absorptive material, Noise Reduction Coefficient (NRC) values of 0.7 – 1



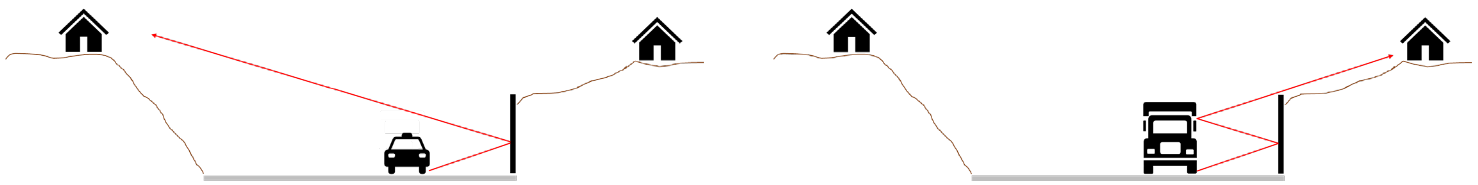




Retaining walls

Noise Benefit
1-2 dB for opposite side reflections Predicted up to 2.5 for parallel barriers and up to 4 dB for truck/barrier reflections

- Treatment helps with multiple or single reflections for depressed parallel walls or single wall



- TNM analysis showed parallel barrier analysis provided an accurate estimate of reflected noise and sound absorptive material
- Percent coverage and placement is dependent on site
- NCHRP study showed treatment can …
    - Reduce reflected noise magnitude
    - Minimize elevation of background noise (L90, L99)
    - May reduce adverse sound wave interaction effects (comb-filtering effect)

Understructure of bridges

Noise Benefit
Measured up to 6 dB for highway and 11 dB in lab Predicted up to 4 dB for sound absorptive treatment

- Sound absorptive treatment on bridge substructures most effective when direct line-of-site blocked

Image: ©2021 Google

- Steel bridge structure: low frequency vibration dampers can help reduce noise
- Depressed road: reflections from overpass best controlled by understructure treatment and sound absorptive pavement

Tunnels

Noise Benefit
Measured 5-10 dB for sound absorptive treatment Predicted 4 dB for surface roughening

- Noise propagates out from tunnel opening
- Absorptive treatment effectiveness dependent on …
  - Tunnel/receptor geometry
    - Angle to tunnel axis: greater angle + greater length of treatment = greater noise reduction (limit to reduction past 45 degrees)
  - Cross-section size of tunnel (minor effect)
  - Skewing the opening (minor effect)
  - Trumpet form opening (strong effect)
    - Directs sound in direction of tunnel axis, decreases other directions

Implementations by Receptors or Local Governments

- Site planning
- Building design
- Construction methods

Implementations by Receptors or Local Governments

Strategy	Noise Benefit	Costs ($-$$$$$)	Context Appropriateness
Site Planning	Up to 3 dB reduction when distance to roadway is doubled 10 dB+ reduction when non-sensitive buildings shield sensitive areas	$ when considered early	New development
Building Design	Up to 13 dB reduction by placing the sensitive rooms farthest from the highway	$ when considered early	New development or redevelopment
Construction Methods	Up to 35 dB interior reduction because of construction methods and materials	$$-$$$$	New development or redevelopment

- Strategies are not directly implementable by State DOTs
- Property owners and land developers depend upon local government to provide guidance
- State DOTs may be asked to assist local government

Guidance and references

- *The Audible Landscape: A Manual for Highway Noise and Land Noise and Land Use* (FHWA 1974)
- *Growing Neighborhoods in Growing Corridors: Land Use Planning for Highway Noise* (Montana DOT 2008)
- *Entering the Quiet Zone – Noise Compatible Land Use Planning* (Texas Southern University 2002)
- *Clark County Nevada Building Department*

  http://clarkcounty-nv.elaws.us/code/coor_title22_ch22.22

Guidance and references

- Land uses:
  - Identify noise compatible land uses and noise sensitive land uses
    - Includes using noise contours to position these land uses
  - Place less noise-sensitive land uses next to highways including retail stores, warehouses, industrial operations, agriculture, and mining

- Site planning: reduce noise impacts by utilizing natural terrain, open space, and building placement to shield noise-sensitive areas

- Building design: consider highway noise when developing room layout, window placement, balcony, or open space

- Construction methods: consider noise transmission through walls, windows, doors, ceilings, and floors

FHWA Noise Compatible Land Use Planning

Application of Findings

Choosing a Strategy

- Process starts with consideration of context appropriateness, considering roadway configuration and other elements:
  - Noise source / path / receptor geometry
  - General site ground type
  - Other site-specific considerations
- Will there be limitations/advantages for strategies due to …
  - The defined project area? (e.g., consider ROW width, water table, strategies that may already be included as part of design)
  - The general site parameters? (e.g., consider site ground type, % heavy trucks)
  - The receptor locations? (e.g., consider receptor elevation in relation to vehicle noise source elevations)
- Process continues with desired noise reduction and cost
  - Certain strategies may be eliminated, although combinations of strategies could be explored

Practitioner's Handbook

- Procedural screening of alternate noise reduction strategies

- Four-step process
  1. Determine appropriate roadway type for your highway project
  2. Review Roadway Type vs Strategy Matrix to extract eligible strategies (includes relative costs)
  3. Read through overviews of eligible strategies to refine selection
  4. Use flowchart for each strategy of interest to determine the approximate maximum potential noise reduction

- Prior to recommending any strategy for implementation, practitioner must consider policy implications and conduct site specific investigations to more accurately predict noise reduction

Roadway Type vs Strategy Matrix (Step 2)

	Relative Cost	2-lane narrow street	2-lane wide street	4-lane narrow street	4-lane wide street	4-lane narrow freeway/highway	4-lane wide freeway/highway	8-lane narrow freeway/highway	8-lane wide freeway/highway
On-Road Design Strategies									
Quieter Bridge Decks and Joints	$$-$$$$	****	****	****	****	****	****	****	****
Quieter Rumble Strip Design	$-$$$	****	****	****	****	****	****	****	****
Quieter Pavements	$$-$$$$	****	****	****	****	****	****	****	****
Highway Design Strategies									
Horizontal / Vertical Alignment	$$$$-$$$$$	****	****	****	****	****	****	***	***
Solid Safety Barriers	$$	***	***	***	***	****	****	**	**
Separation Zones	$	****	***	***	**	n/a	n/a	n/a	n/a
Right-of-way Design Strategies									
Low-Height Berms	$-$$$	****	****	****	****	****	****	****	****
Vegetated Screens	$-$$$	***	***	***	***	***	***	***	***
Vegetated Swales and Basins	$	***	***	***	***	**	**	**	**
Acoustically Soft Ground	$$-$$$	***	***	***	***	***	***	**	**
In-ground Treatments	$$$	***	***	***	***	***	***	***	***
Above-ground Treatments	$$-$$$$	***	***	***	***	***	***	***	***
Solar Panels	$$-$$$$	****	****	****	****	****	****	****	****
Operations Mgmt. Strategies									
Speed Restrictions	$-$$	**	**	**	**	**	**	**	**
Truck Restrictions	$-$$	***	***	***	***	***	***	***	***
Sound Absorptive Treatments									
Retaining Walls	$$-$$$	**	**	**	**	**	**	**	**
Understructure of Bridges	$$-$$$$	****	****	****	****	****	****	****	****
Tunnels	$$-$$$$	****	****	****	****	****	****	****	****
Strategies Implemented by Receptors or Local Governments									
Site Planning	$	***	***	***	***	***	***	***	***
Building Design	$	****	****	****	****	****	****	****	****
Construction Methods and Materials	$$-$$$$	****	****	****	****	****	****	****	****

$ minimal cost -- $$$$$ very high cost

**** Likely to be very effective, *** Likely to be effective, ** Likely to be minimally effective, * Likely to be barely effective, n/a = not applicable

Highlighted cells are strategies that merit consideration for the given roadway type

Roadway Type vs Strategy Matrix (Step 2)

	Relative Cost	2-lane narrow street	2-lane wide street	4-lane narrow street	4-lane wide street	4-lane narrow freeway/highway	4-lane wide freeway/highway	8-lane narrow freeway/highway	8-lane wide freeway/highway
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Quieter Rumble Strip Design	$-$$$	****	****	****	****	****	****	****	****
Quieter Pavements	$$-$$$$	****	****	****	****	****	****	****	****
Highway Design Strategies									
Horizontal / Vertical Alignment	$$$$-$$$$$	****	****	****	****	****	****	***	***
Solid Safety Barriers	$$	***	***	***	***	****	****	**	**
Separation Zones	$	****	***	***	**	n/a	n/a	n/a	n/a
Right-of-way Design Strategies									
Low-Height Berms	$-$$$	****	****	****	****	****	****	****	****
Vegetated Screens	$-$$$	***	***	***	***	***	***	***	***
Vegetated Swales and Basins	$	***	***	***	***	**	**	**	**
Acoustically Soft Ground	$$-$$$	***	***	***	***	***	***	**	**
In-ground Treatments	$$$	***	***	***	***	***	***	***	***
Above-ground Treatments	$$-$$$$	***	***	***	***	***	***	***	***
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Sound Absorptive Treatments									
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Construction Methods and Materials	$$-$$$$	****	****	****	****	****	****	****	****

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Roadway Type vs Strategy Matrix (Step 2)

"likely to be very effective"

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Vegetated Swales and Basins	$	***	***	***	***	**	**	**	**
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Above-ground Treatments	$$-$$$$	***	***	***	***	***	***	***	***
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Construction Methods and Materials	$$-$$$$	****	****	****	****	****	****	****	****

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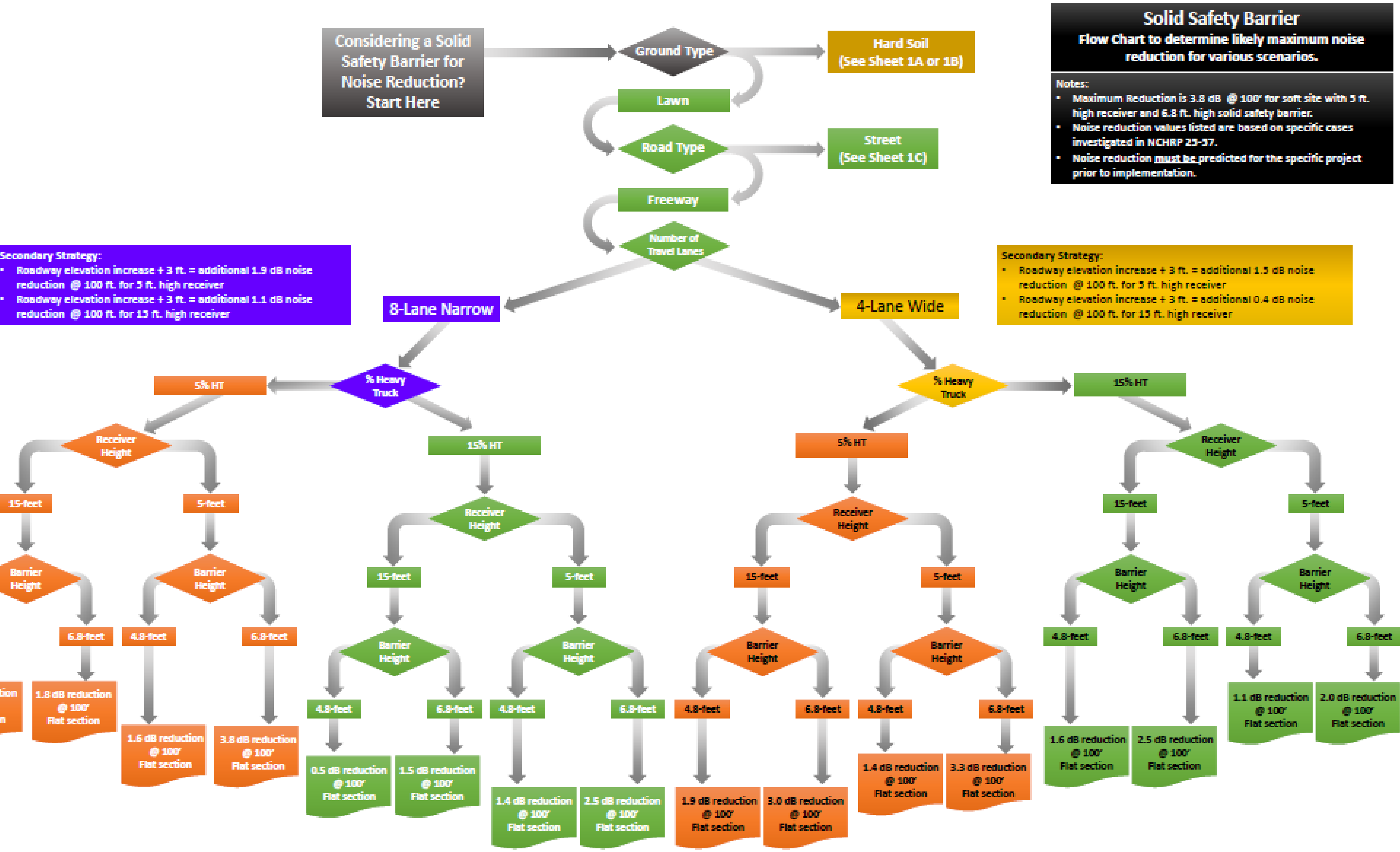
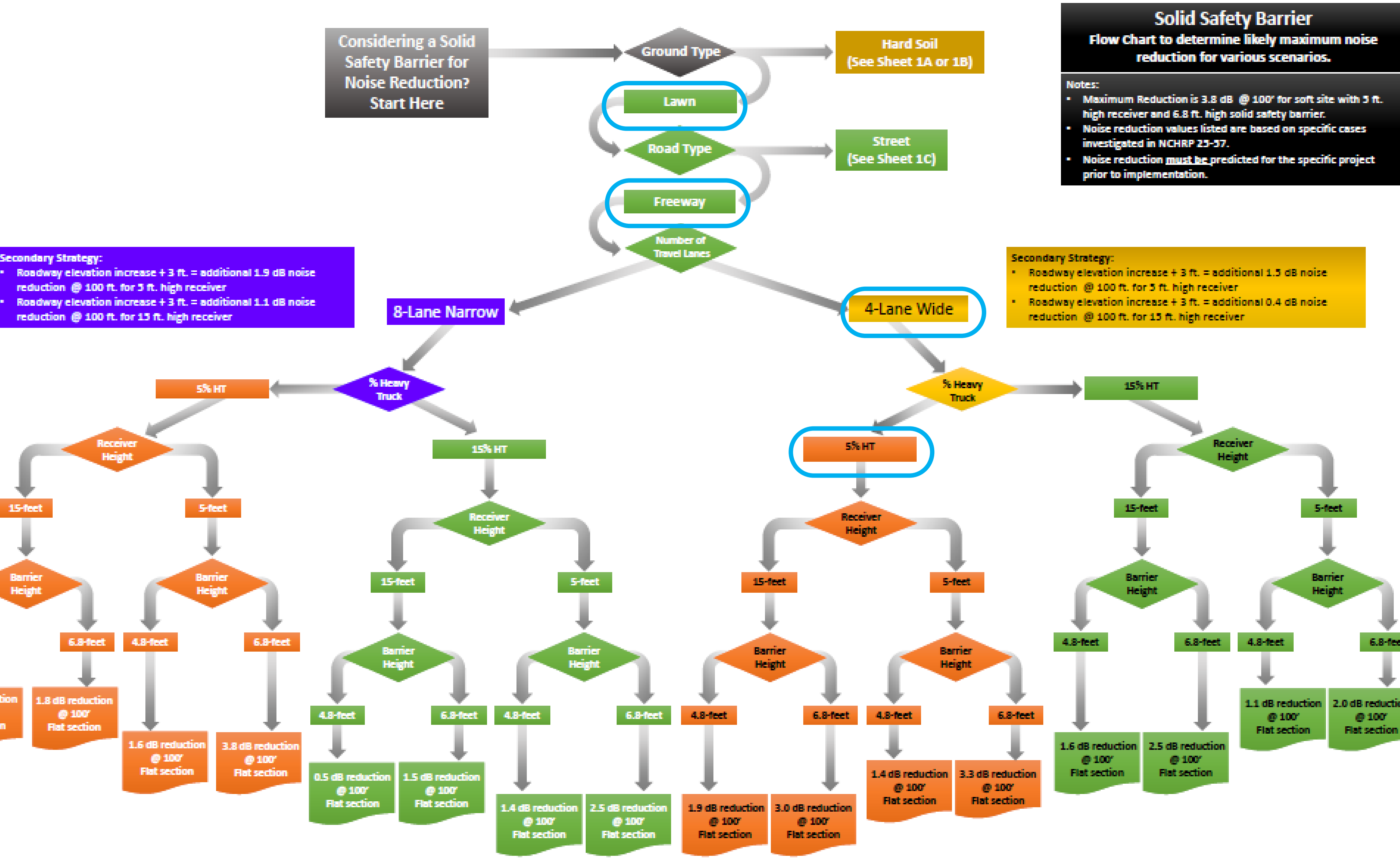
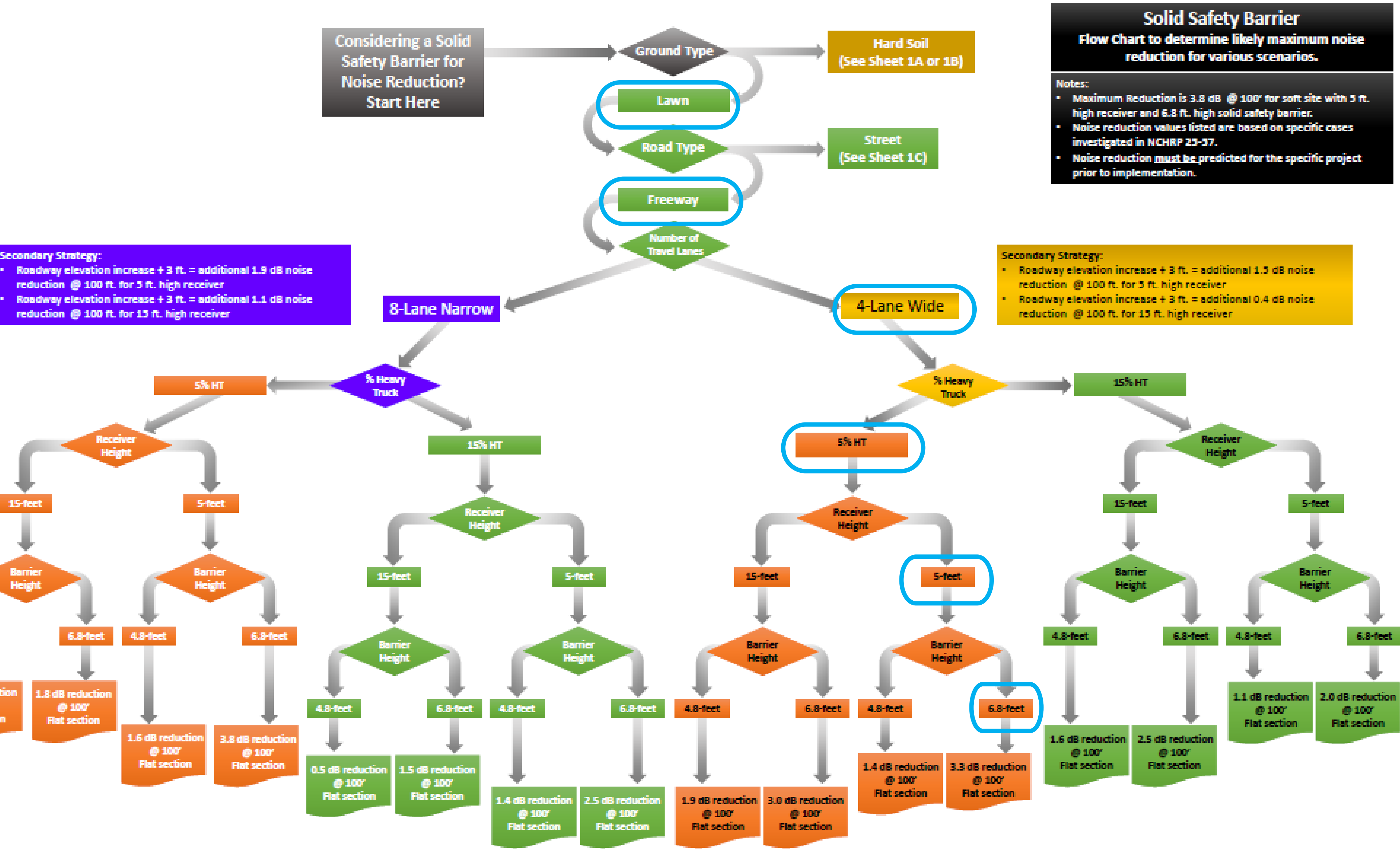
Example flowchart (Step 4)



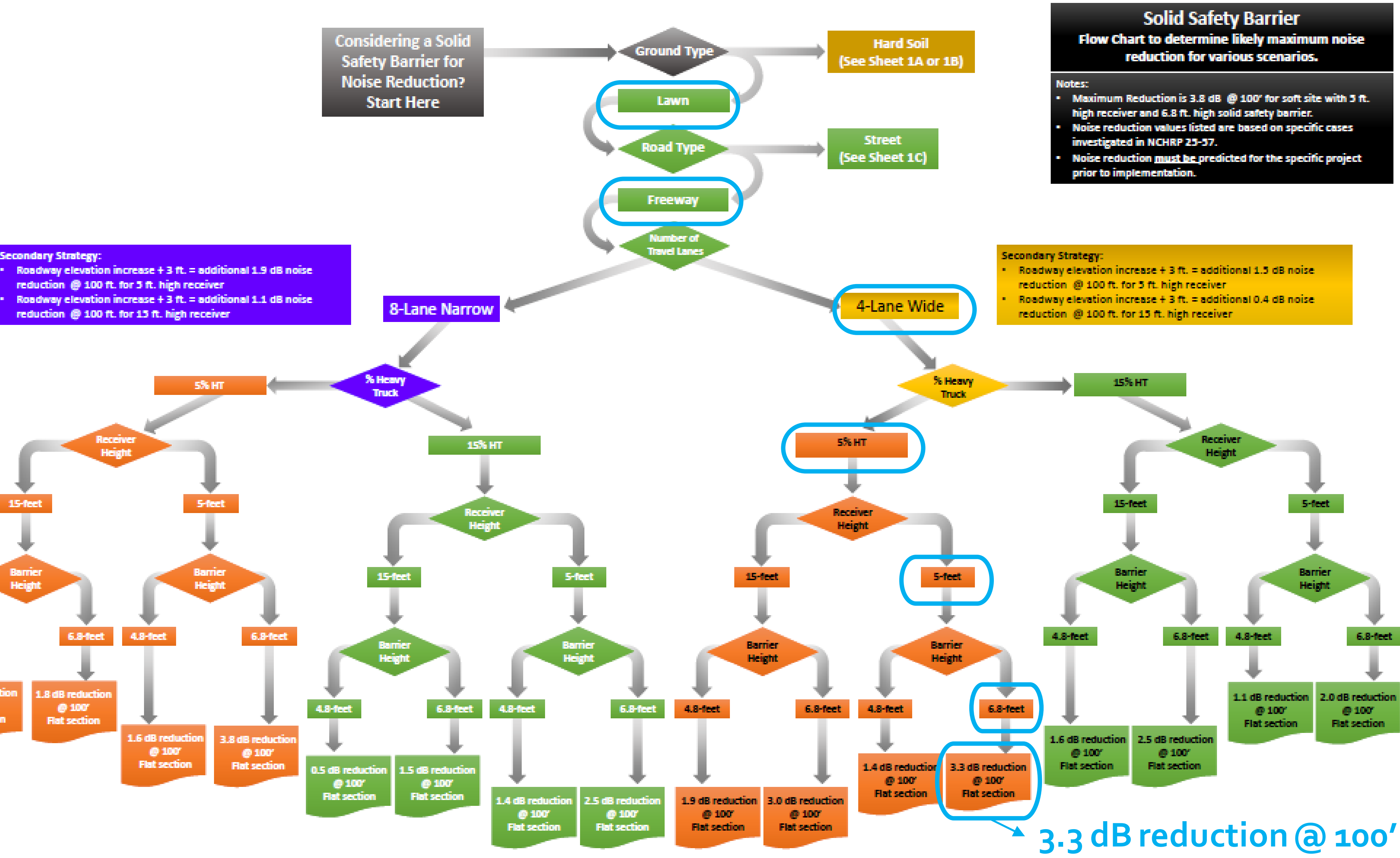
Example flowchart (Step 4)



Example flowchart (Step 4)



Example flowchart (Step 4)



Conclusions

Conclusions

- Opportunities to apply alternative noise reduction strategies include:
    1. When a barrier cannot be constructed due to site constraints, safety considerations, or Federal and State policies on reasonable expenditure per benefited receptor
    2. When applying the strategies may prevent noise impacts
- Project report and practitioner's handbook allow identification of viable strategies
    - Options include 14 primary strategies with sub-strategies also discussed
- Some strategies are currently implementable, some require further investigation

Today’s presenters

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engineers, architects, planners

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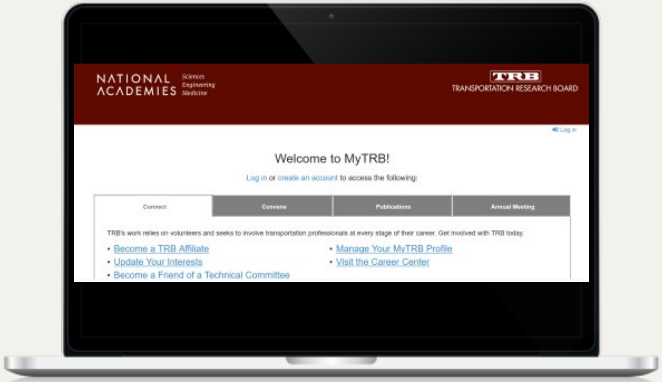

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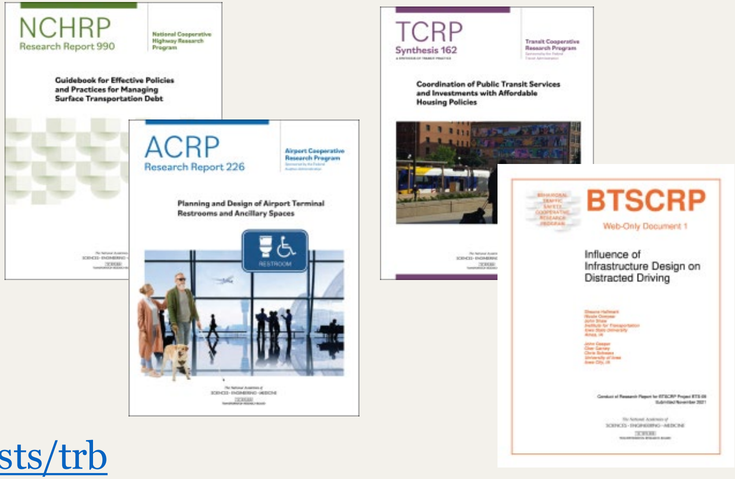

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