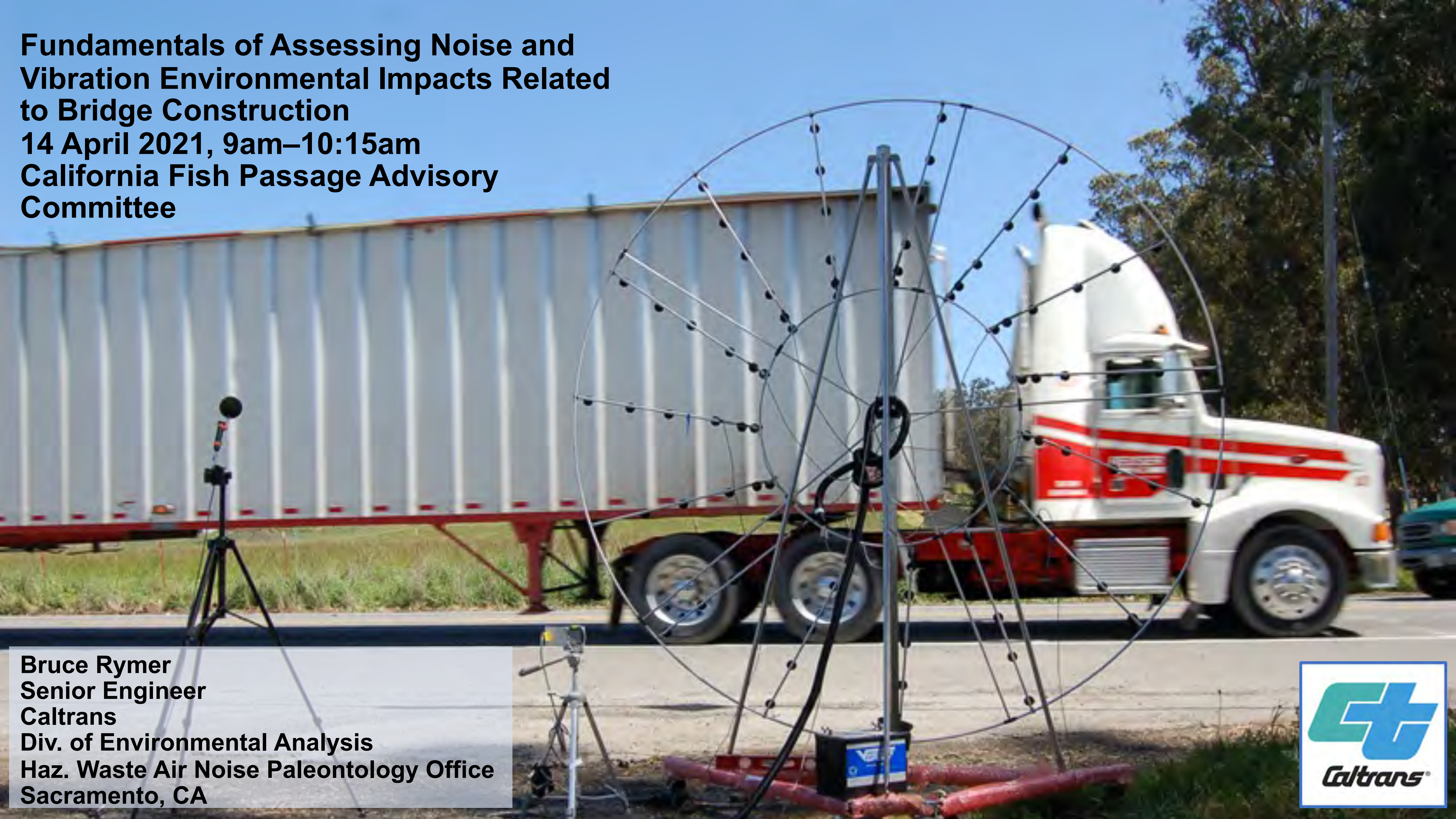
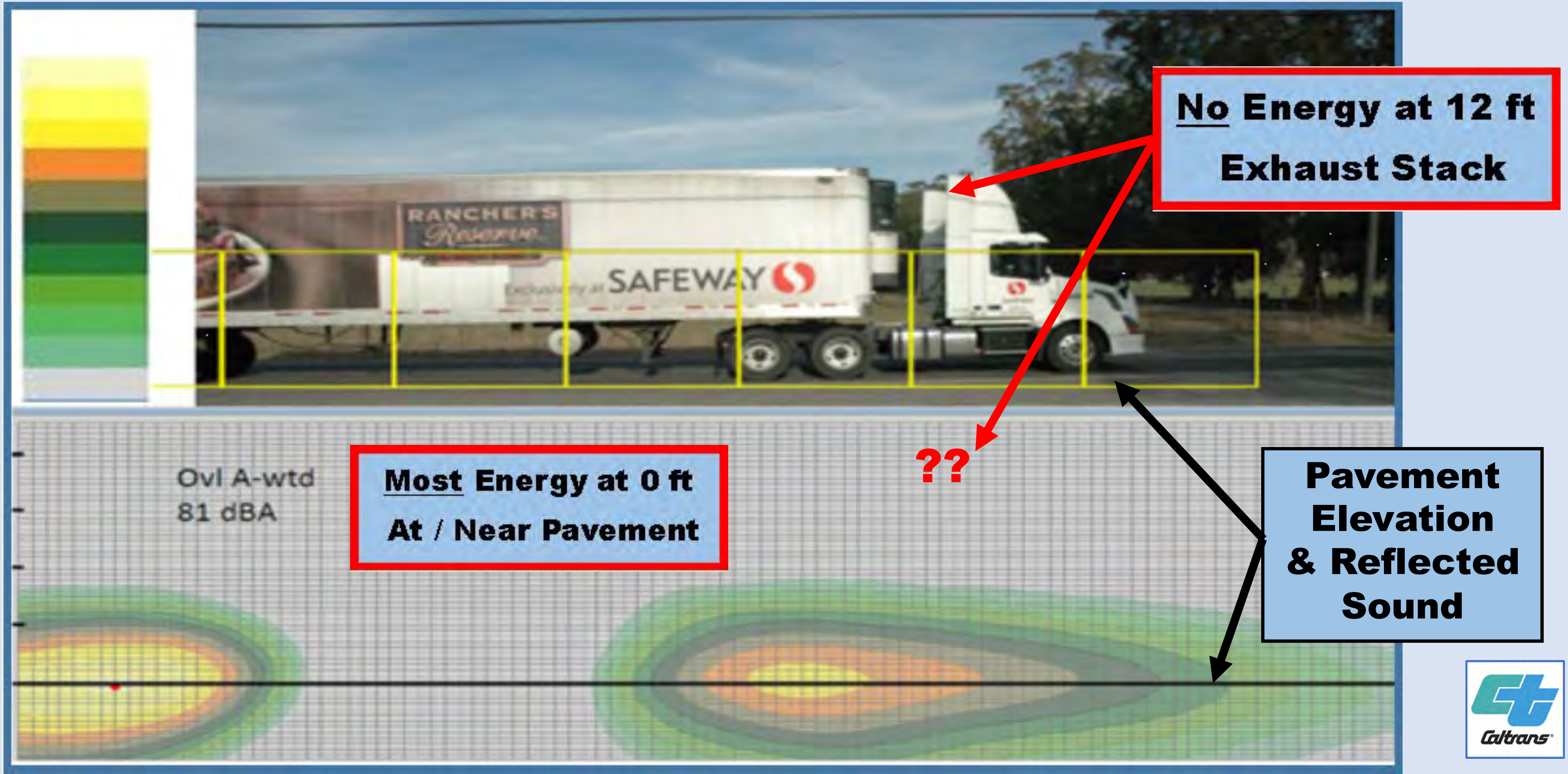
# Fundamentals of Assessing Noise and Vibration Environmental Impacts Related to Bridge Construction
# 14 April 2021, 9am–10:15am
# California Fish Passage Advisory Committee




Bruce Rymer
Senior Engineer
Caltrans
Div. of Environmental Analysis
Haz. Waste Air Noise Paleontology Office
Sacramento, CA


Caltrans

# Beamforming – 'Acoustic Photography'



# Acoustic Measurement Technologies

## ----Old----

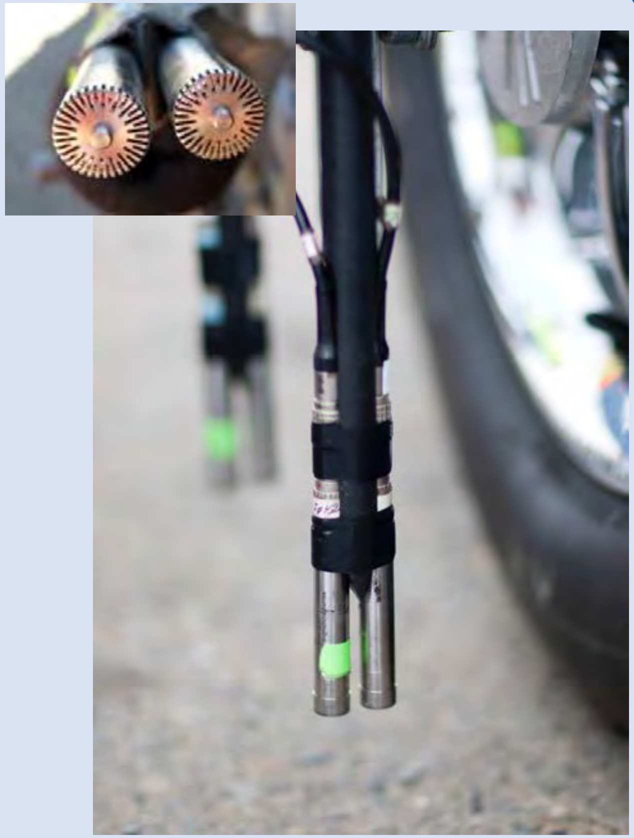

Source: Wikipedia

Single Microphone
– Sound Pressure Level
(SPL)


Source: Wikipedia

Hydrophone
– Underwater
Sound Pressure Level
(SPL)

## ----New----(NAS Research)



(Pioneered by Caltrans)

Dual Microphone Probe
w/ signal processing
– Sound Intensity (SI)
Focuses measurements

Multi-Microphone Array
w/ signal processing
– Beam Forming or
Acoustic Camera
localizes sound sources

GM

U.S. Department of Transportation
Federal Highway Administration

**General Motors**
**Caltrans**
**FHWA - Pavements**
**TPF 5-135 SDOTs,**
**Industry & Academia**
**NAS / NCHRP**
**AASHTO**

Minnesota Department of Transportation

International Grooving & Grinding Association

WSDOT

Rutgers Center for Advanced Infrastructure and Transportation

State of North Carolina Department of Transportation

CTR The University of Texas at Austin Center for Transportation Research

TPF Transportation Pooled Fund Program

UCPRC University of California Davis • Berkeley Pavement Research Center

American Association of State Highway and Transportation Officials
AASHTO

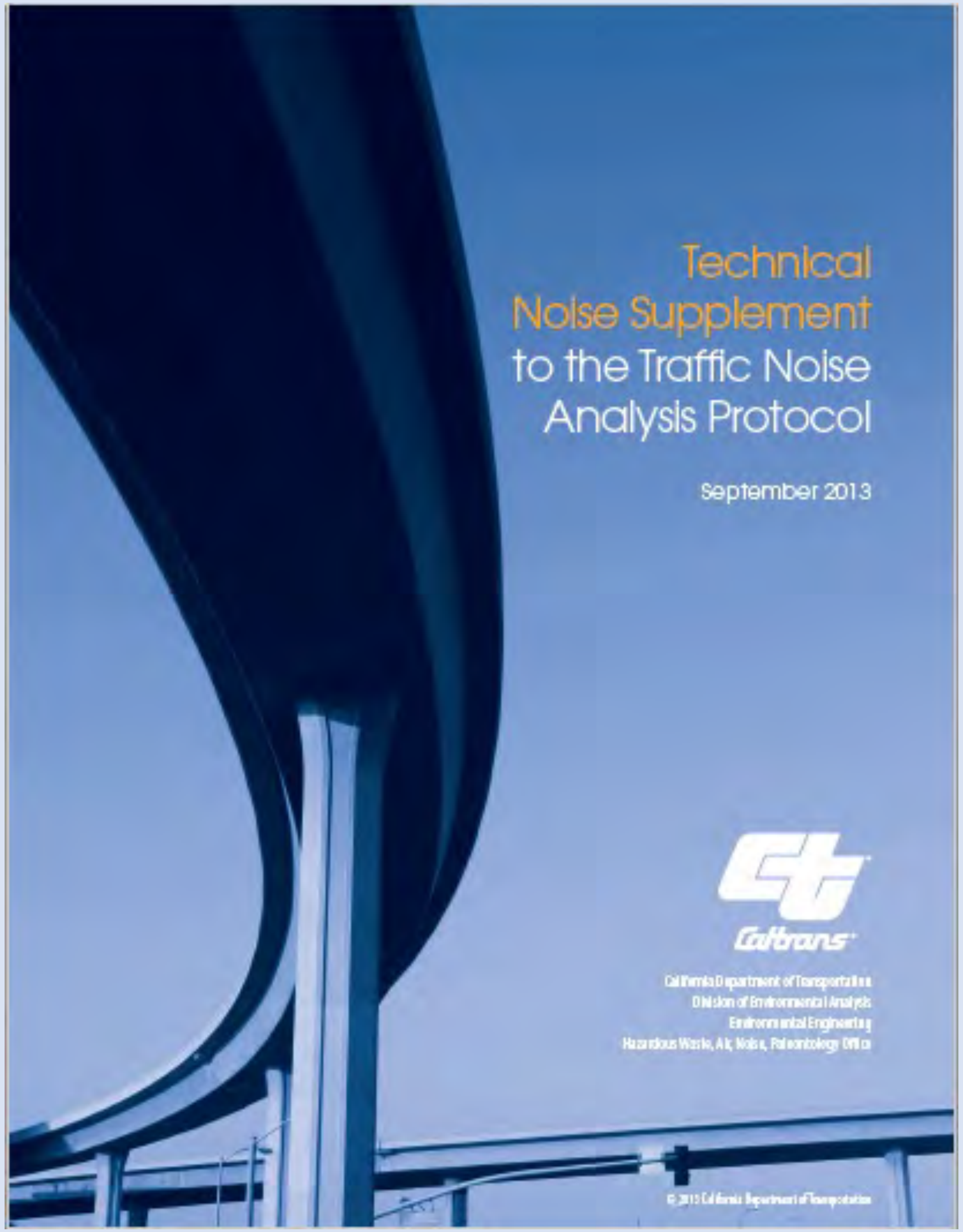
**Standard T 360-16**

NCHRP National Cooperative Highway Research Program

Texas Department of Transportation

FDOT

Caltrans




# Caltrans Technical Noise Supplement (TeNS)

## Basics of Acoustics as Applied to Traffic and Construction Noise Levels

Section 1 Intro Overview

Section 2 Basics of Highway Noise
- Physics
- Sound Pressure Levels
- Acoustic Arithmetic
- Sound Propagation
- Ground Absorption
- Atmospheric Effects

Section 3 Measurements and Instrumentation
- Construction Noise
- Instrumentation Basics
- Meteorological Considerations

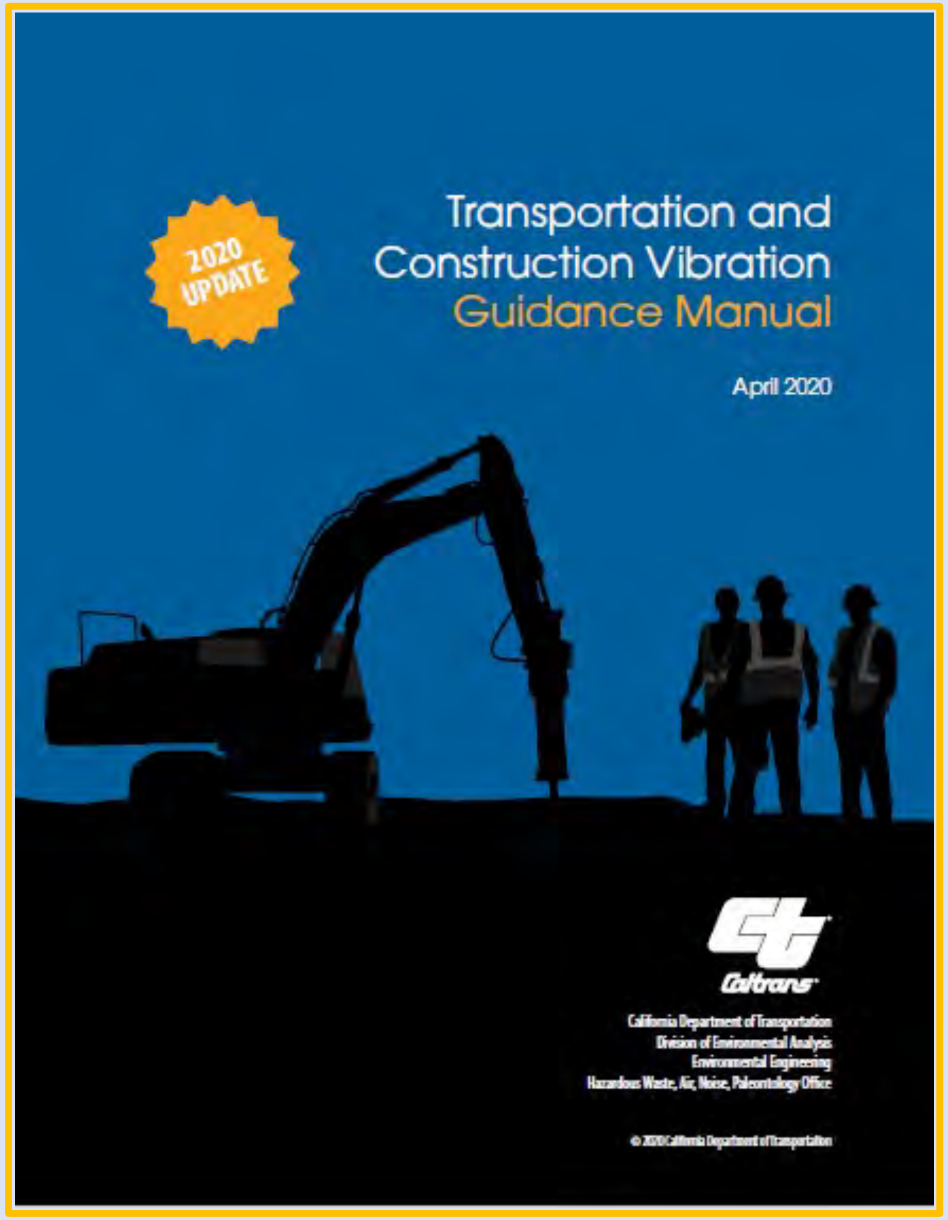
Section 4 Detail Analysis for Traffic Noise Impacts

Section 5 Noise Barrier Design Considerations

Section 6 Noise Study Report

Section 7 Non-Routine Considerations & Issues
- Abatement at Source-Path-Receiver
- Earthborne Vibration

https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/tens-sep2013-a11y.pdf

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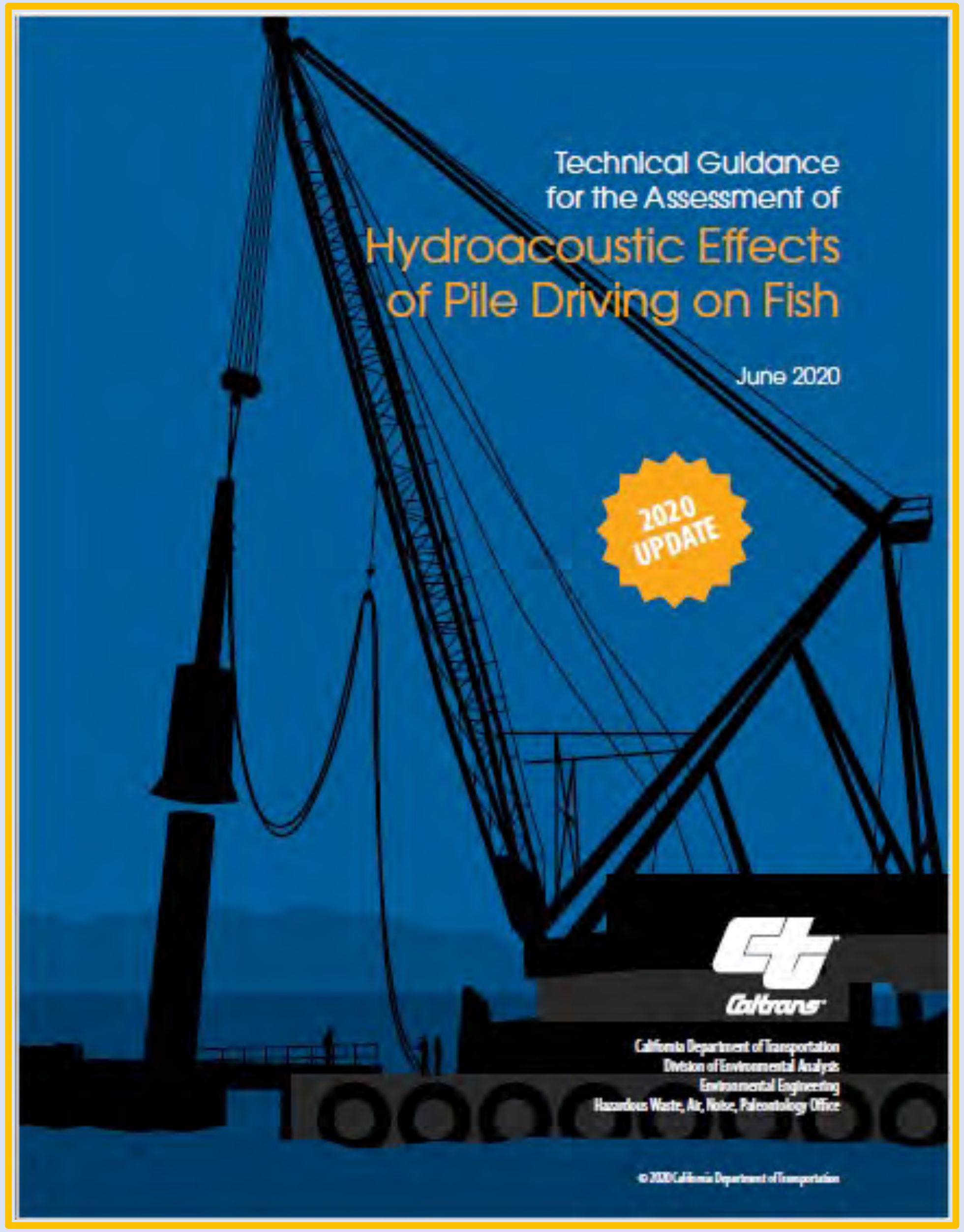
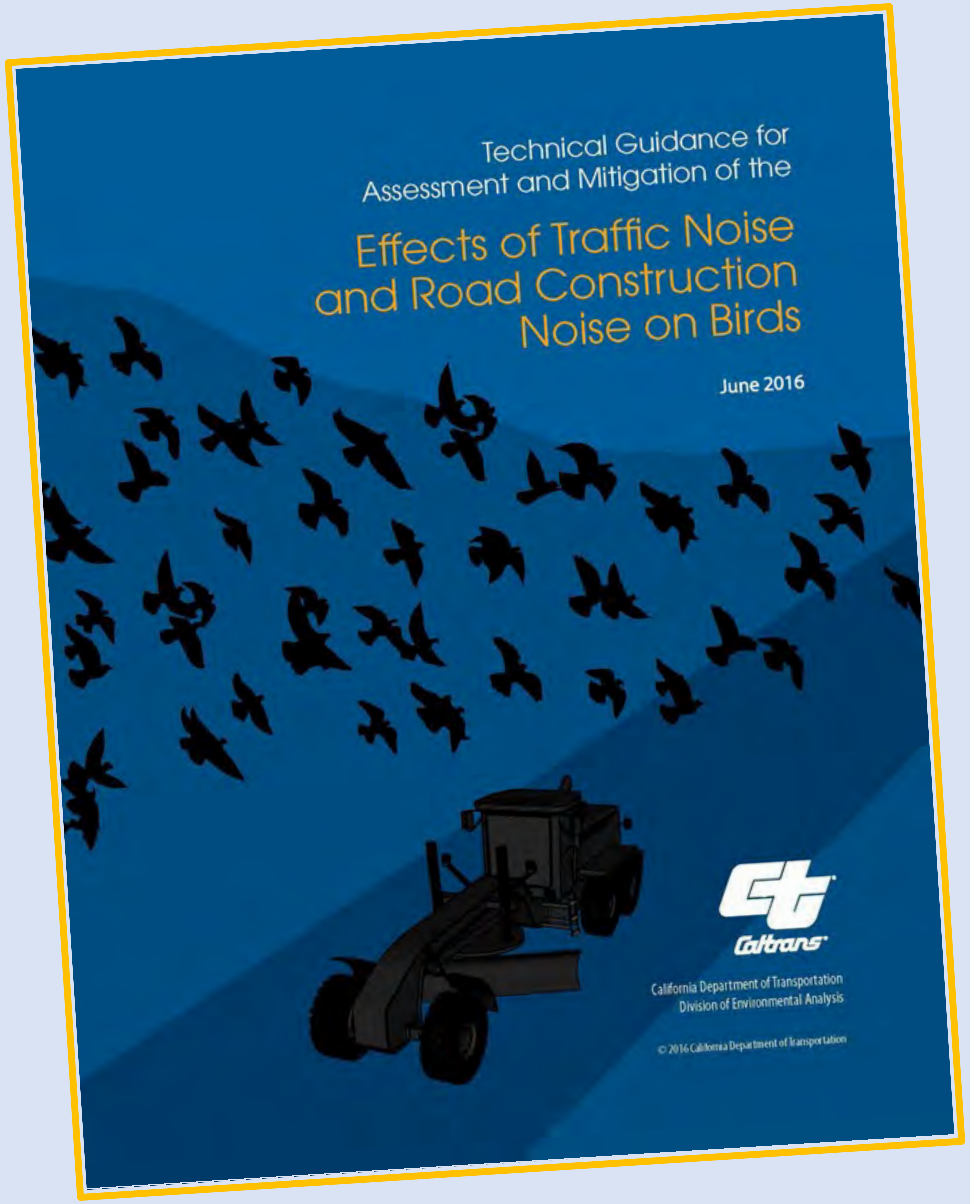
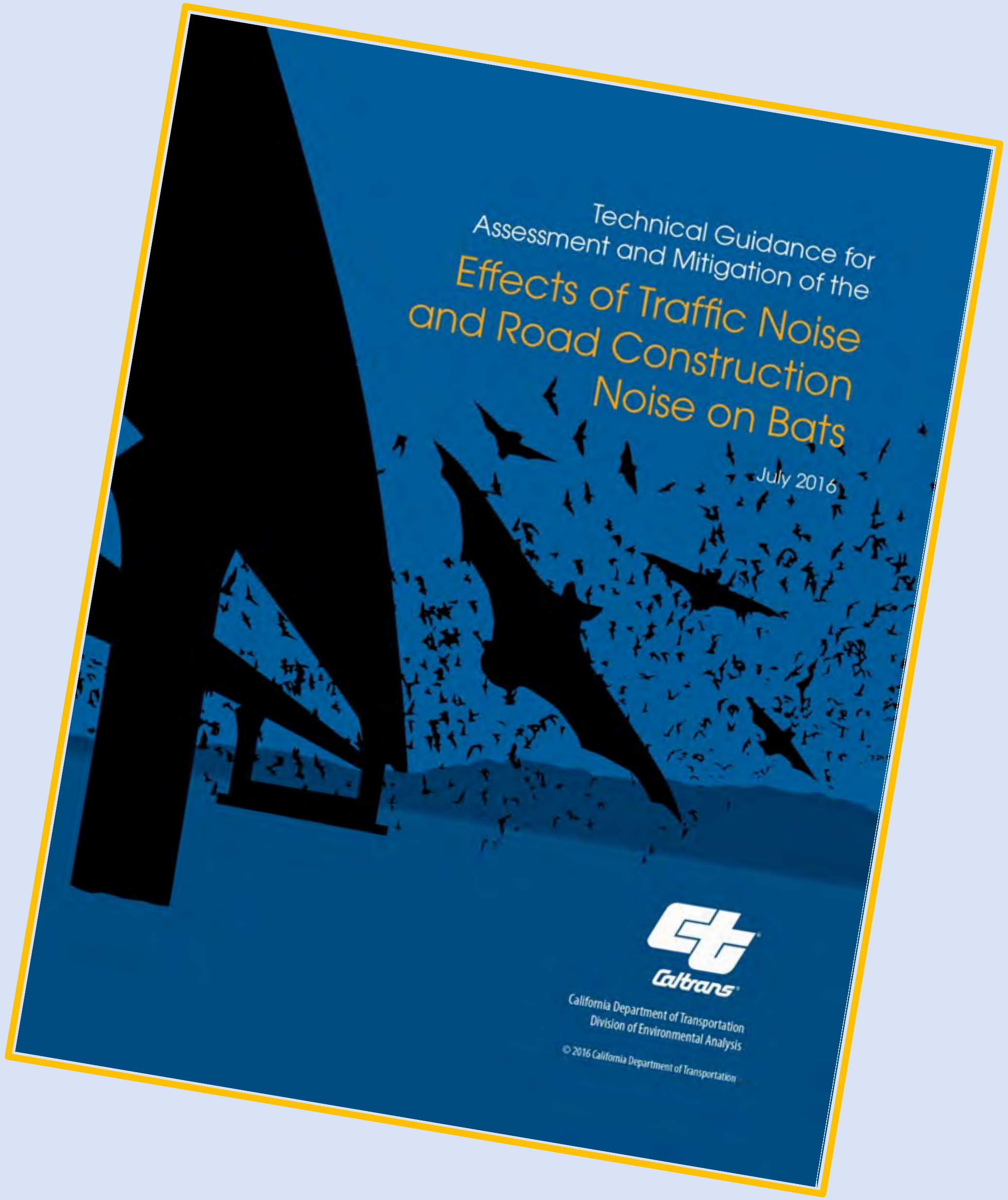



https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/hydroacoustic-manual.pdf




https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/noise-effects-on-birds-jun-2016-a11y.pdf

https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/noise-effects-on-bats-jul2016-a11y.pdf

**Think in terms of wave energy creating positive and negative pressure fluctuations in air, water, and ground/solid material.**

- **Hydroacoustics Pressure Fluctuation of Water**
- **Noise Pressure Fluctuation of Air**
- **Vibration Pressure Fluctuation Ground/Solid Material**


**Energy reduces (attenuates) with distance as it spreads outward from origin**

### What Does Sound Look Like?

Interesting 3-minute video showing impulse (transient) noise traveling through air.

https://www.youtube.com/watch?v=px3oVGXr4mo

# Energy Levels & Logarithms


**What is the LOUDEST Sound Ever Heard?**

https://www.youtube.com/watch?v=3W5-ZJ-TJTY

# Hydroacoustic Scale is Different

## Typical Underwater Sound Pressure Levels

| Sound Source | Sound Pressure Levels | |
|---|---|---|
| | dB | Pascals |
| High explosives at 100 meters | 220 | 100,00 |
| Air gun array at 100 meters<br>Un-attenuated 24" steel pipe piles at 10 meters | 200 | 10,000 |
| Un-attenuated 12" H-beam piles at 10 meters | 180 | 1,000 |
| Large ship at 100 meters | 160 | 100 |
| Fish trawler (low speed) at 20 meter | 140 | 10 |
| Background with small boat traffic | 100 | 0.1 |
| | 80 | 0.01 |

**Calculation of Sound Pressure Level (SPL):**

$$SPL = 10 \log (p/p_{ref})^2, dB$$

or

$$SPL = 20 \log (p/p_{ref}), dB$$

where $p_{ref}$ is the reference pressure:
for air, $p_{ref} = 20\ \mu Pa$
for water, $p_{ref} = 1\ \mu Pa$

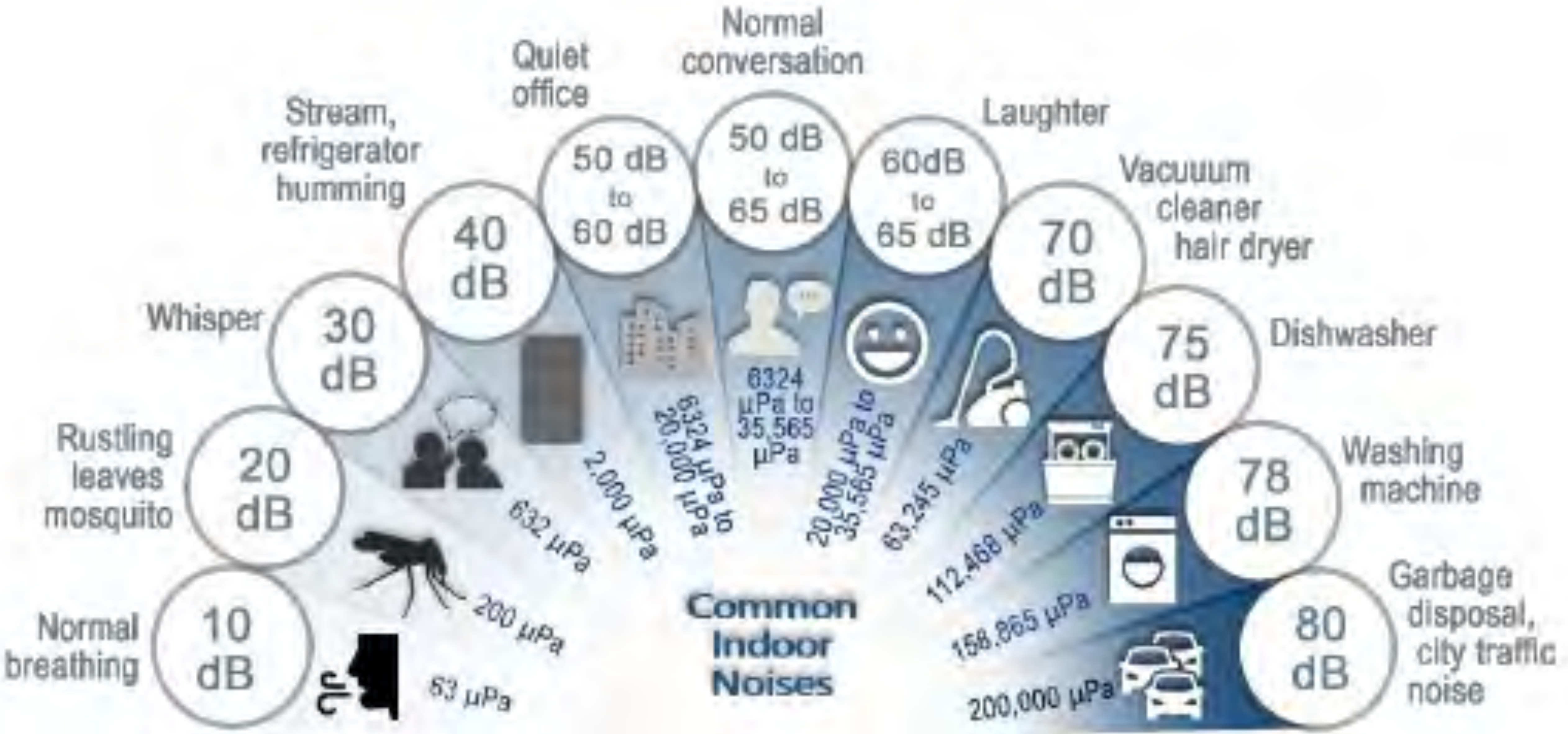
As a result:

$$SPL_{water} = SPL_{air} + 26\ dB$$

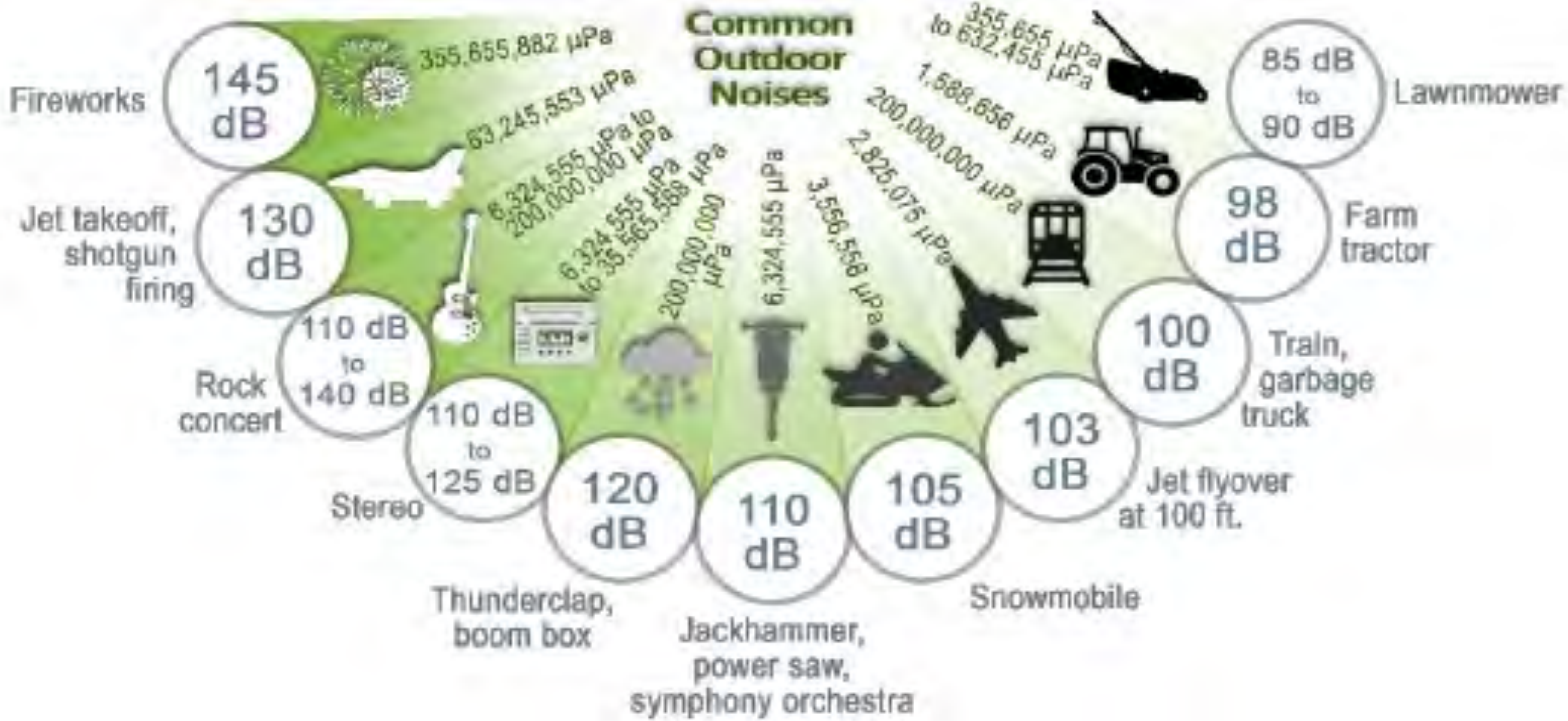
- **Different reference pressure**
- **Not A-weighted (adj. for human hearing)**
- **26 dB louder**

**Caltrans Pile Driving Guidance**

# Common Indoor Noises (in-Air)



# Common Outdoor Noises



# Acoustic Arithmetic

+

**110 dB + 110 dB ≠ ~~220 dB~~ = 113 dB**

## Adding Sound Pressure Levels Using a Simple Table

When combining sound levels, a table such as the following may be used as an approximation.

**Table 2-3.** Decibel Addition

| When Two Decibel Values Differ by: | Add This Amount to the Higher Value: | Example: |
|---|---|---|
| 0 or 1 dB | 3 dB | 70 + 69 = 73 dB |
| 2 or 3 dB | 2 dB | 74 + 71 = 76 dB |
| 4 to 9 dB | 1 dB | 66 + 60 = 67 dB |
| 10 dB or more | 0 dB | 65 + 55 = 65 dB |

# Noise Level, Energy, Perceived Change

| Noise Level Change, (dBA) | Change in Relative Energy ($10^{\pm\Delta dBA/10}$) | Perceived Change | |
|---|---|---|---|
| | | Perceived Change in Percentage ($([2^{\pm\Delta dBA/10}-1] * 100\%)$) | Descriptive Change in Perception |
| +40 | 10,000 | | 16 times as loud |
| +30 | 1,000 | | Eight times as loud |
| +20 | 100 | +300% | Four times as loud |
| +15 | 31.6 | +183% | |
| +10 | 10 | +100% | Two times as loud |
| +9 | 7.9 | +87% | |
| +8 | 6.3 | +74% | |
| +7 | 5.0 | +62% | |
| +6 | 4.0 | +52% | |
| +5 | 3.16 | +41% | Readily perceptible increase |
| +4 | 2.5 | +32% | |
| +3 | 2.0 | +23% | Barely perceptible increase |
| 0 | 1 | 0% | Reference (no change) |

# Identify and Characterize the Energy Source

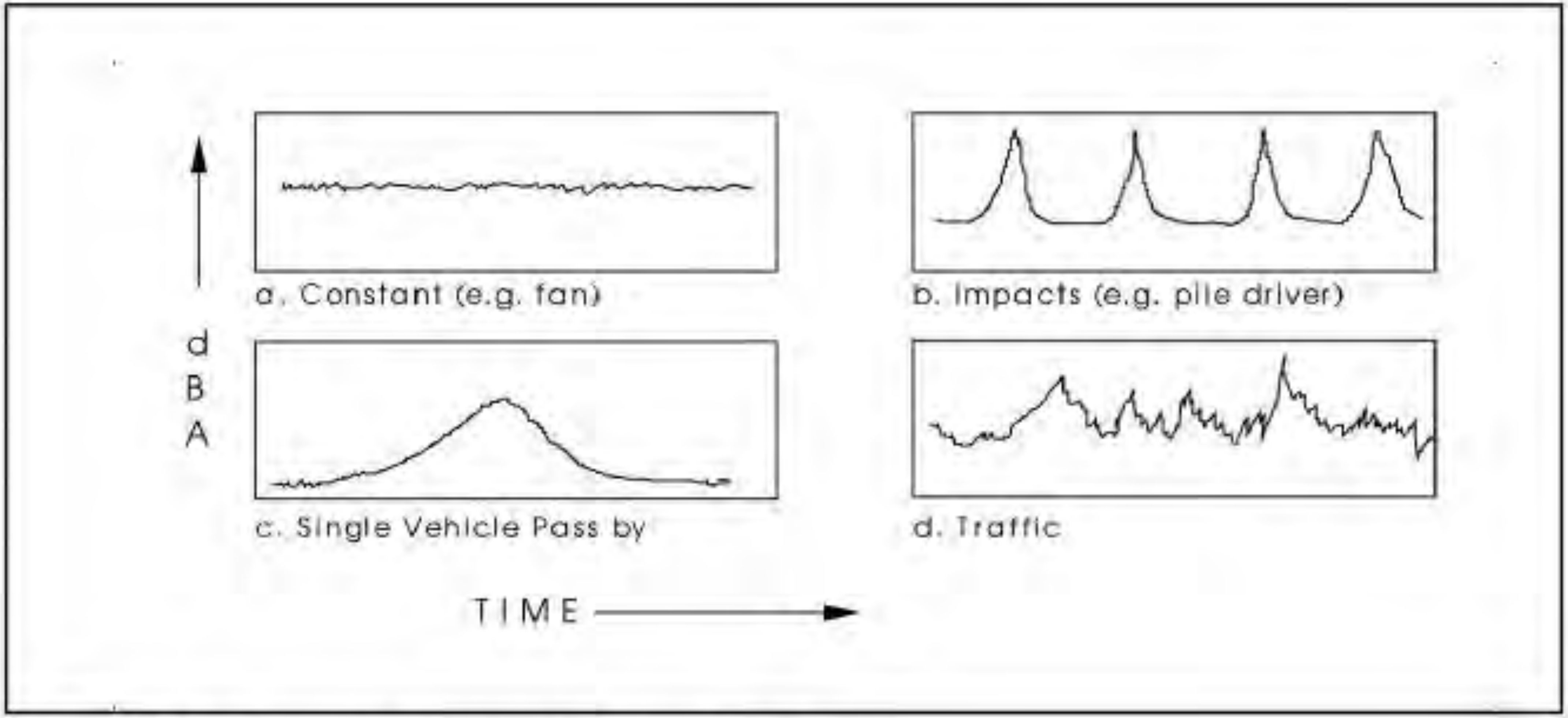



**Figure 2-18.** Different Noise Level vs. Time Patterns

# Source – Path – Receptor

## Air

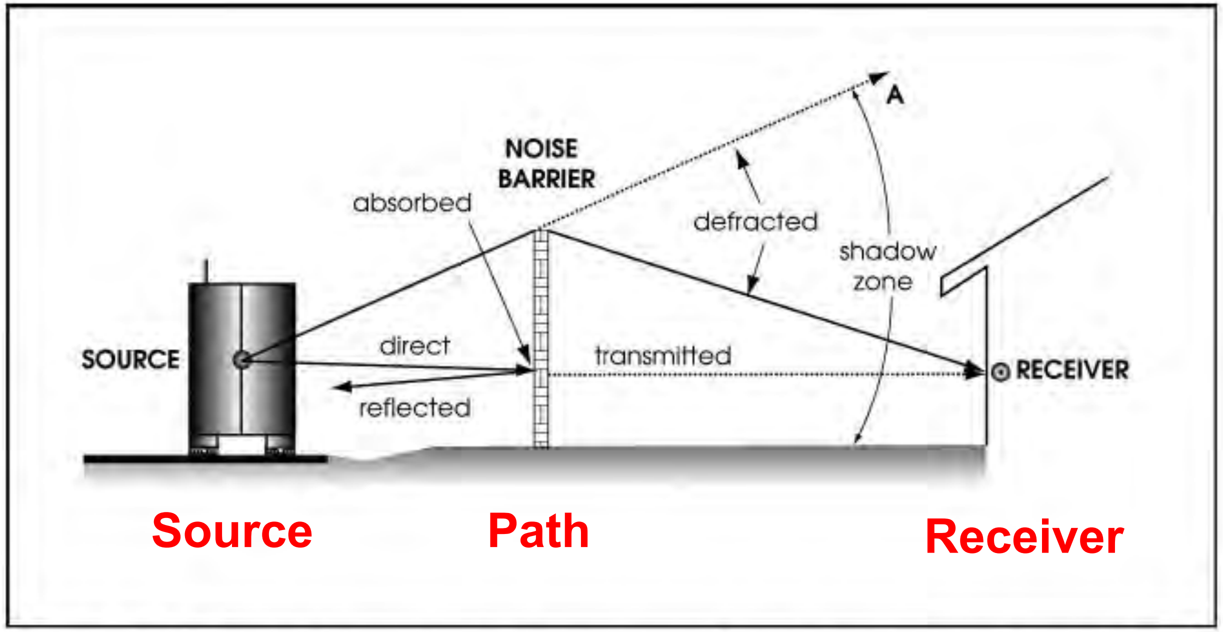



Figure 2-12. Alteration of Sound Paths after Inserting a Noise Barrier between Source and Receiver

Caltrans Technical Noise Supplement (TeNS)

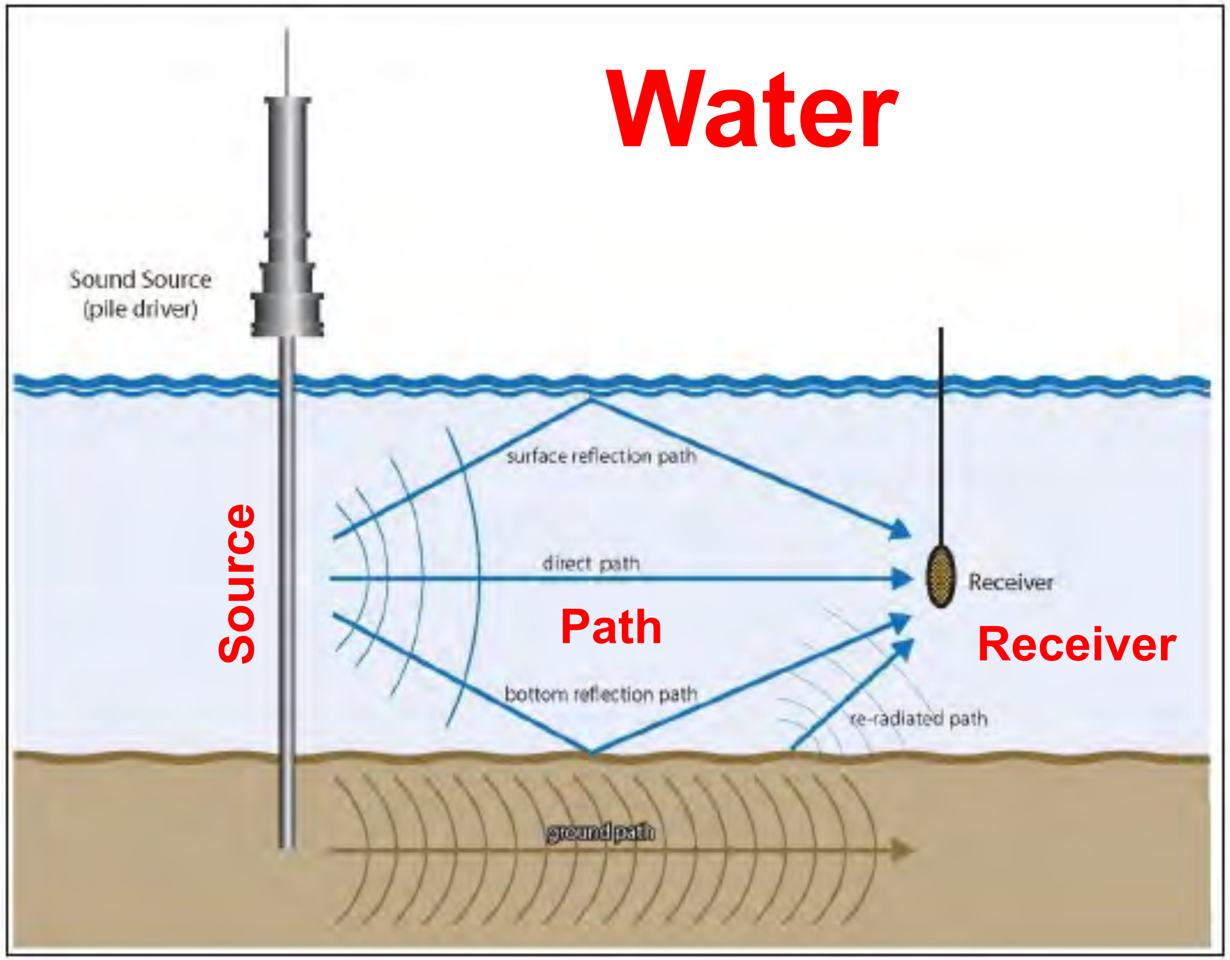
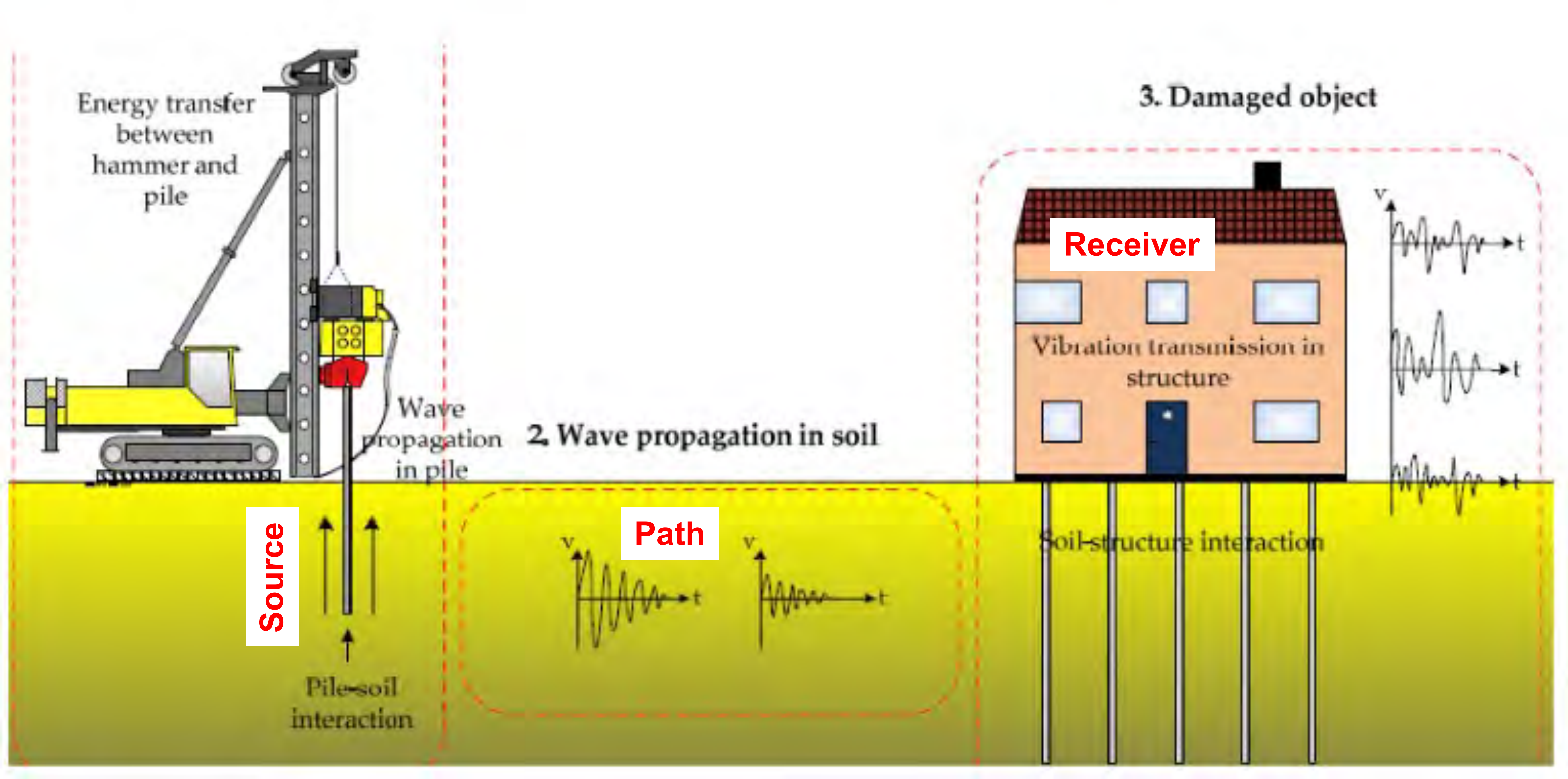



Figure 2-11. Underwater Sound Propagation Paths

Caltrans Pile Driving Guidance

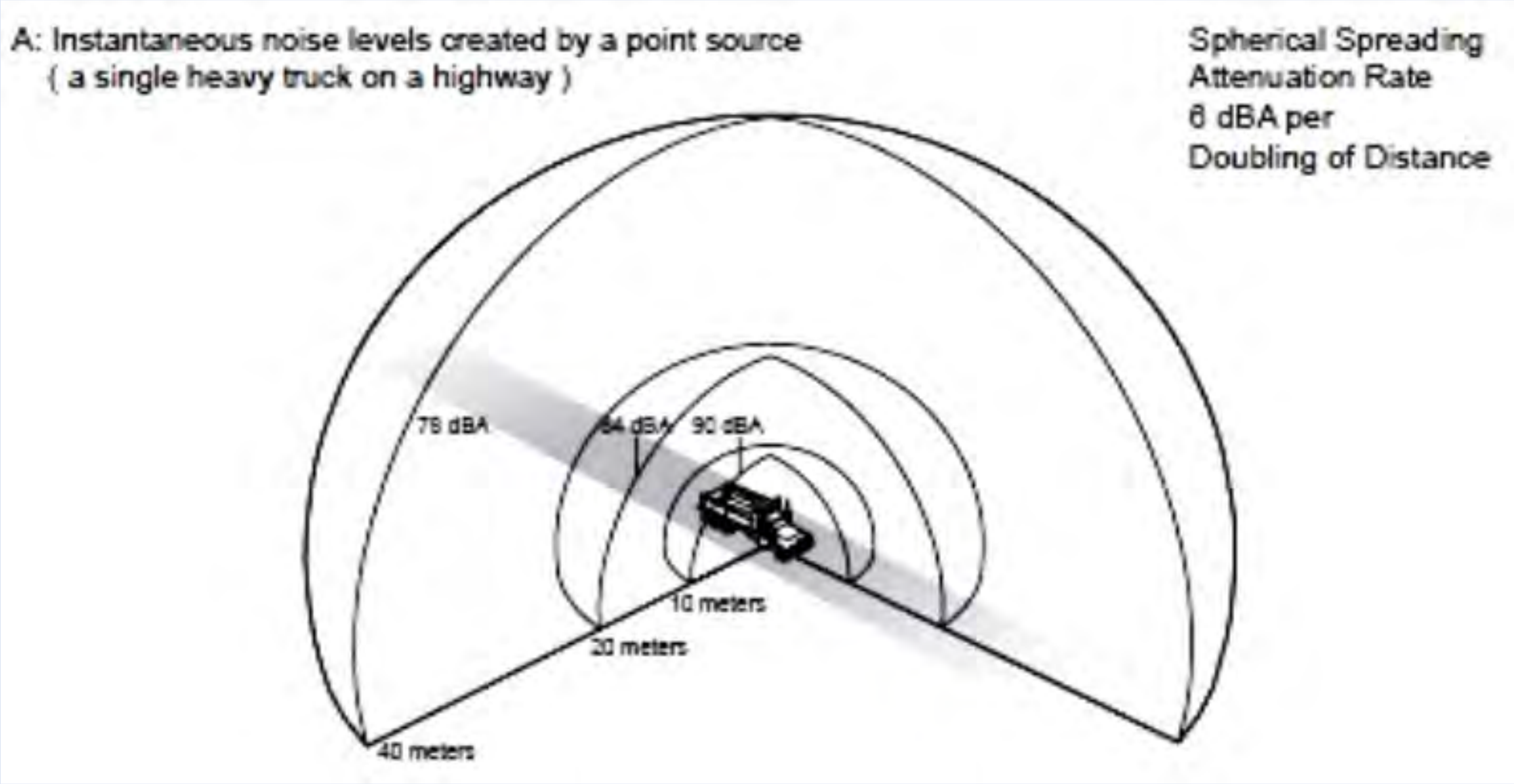
# Source – Path – Receptor

## Ground-Borne Vibrations



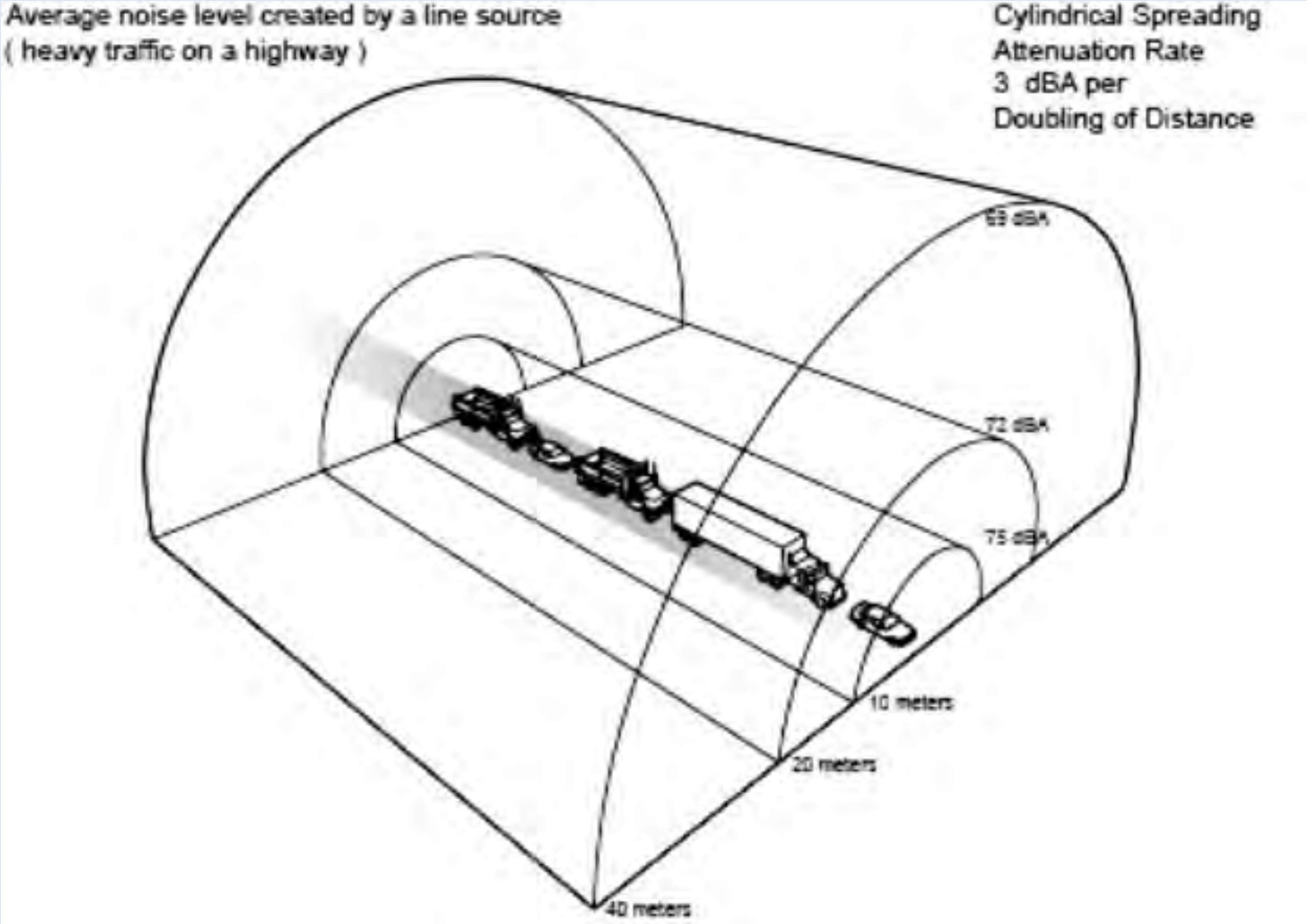

Source: Pile-driving induced vibration in urban environments (Hintze et al. 1997 and Deckner2013)

# Point Energy Source – Spherical Spreading

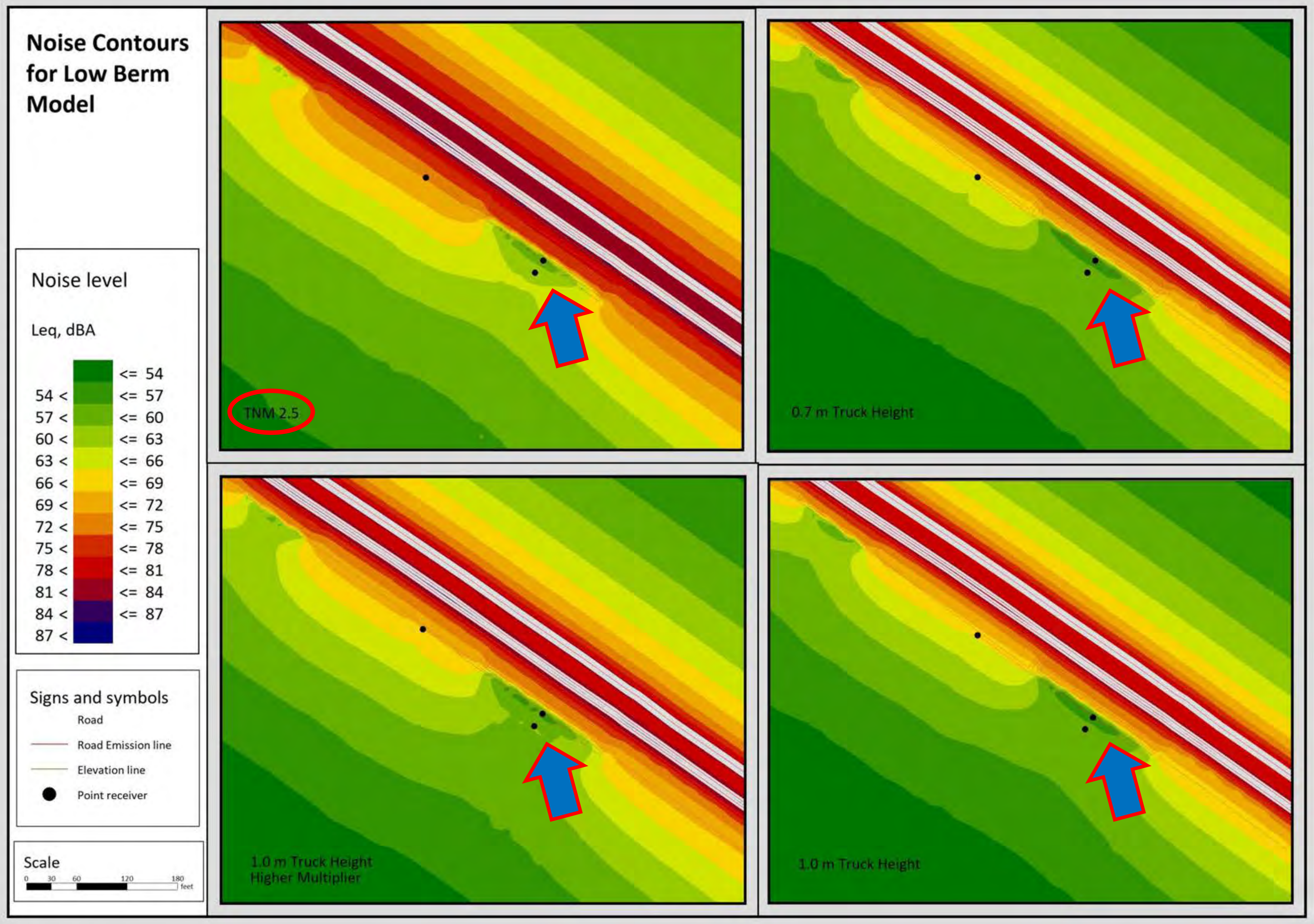



Source: http://sdngnet.com

# Line Energy Source – Cylindrical Spreading



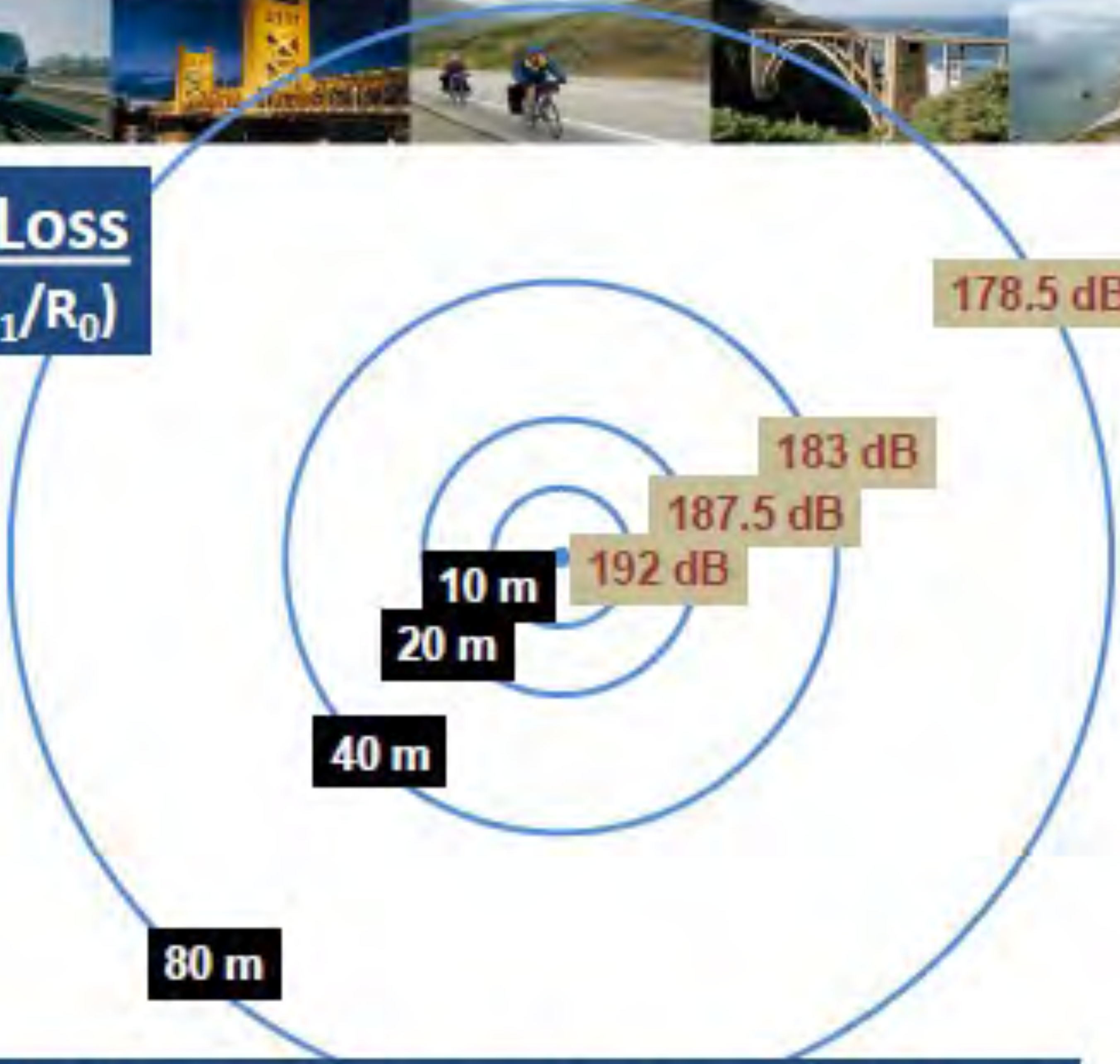

Source: http://sdngnet.com



Noise Contours for Low Berm Model
Noise level
Leq, dBA
<= 54
54 < <= 57
57 < <= 60
60 < <= 63
63 < <= 66
66 < <= 69
69 < <= 72
72 < <= 75
75 < <= 78
78 < <= 81
81 < <= 84
84 < <= 87
87 <
Signs and symbols
Road
Road Emission line
Elevation line
Point receiver
Scale
0 30 60 120 180 feet
TNM 2.5
0.7 m Truck Height
1.0 m Truck Height Higher Multiplier
1.0 m Truck Height

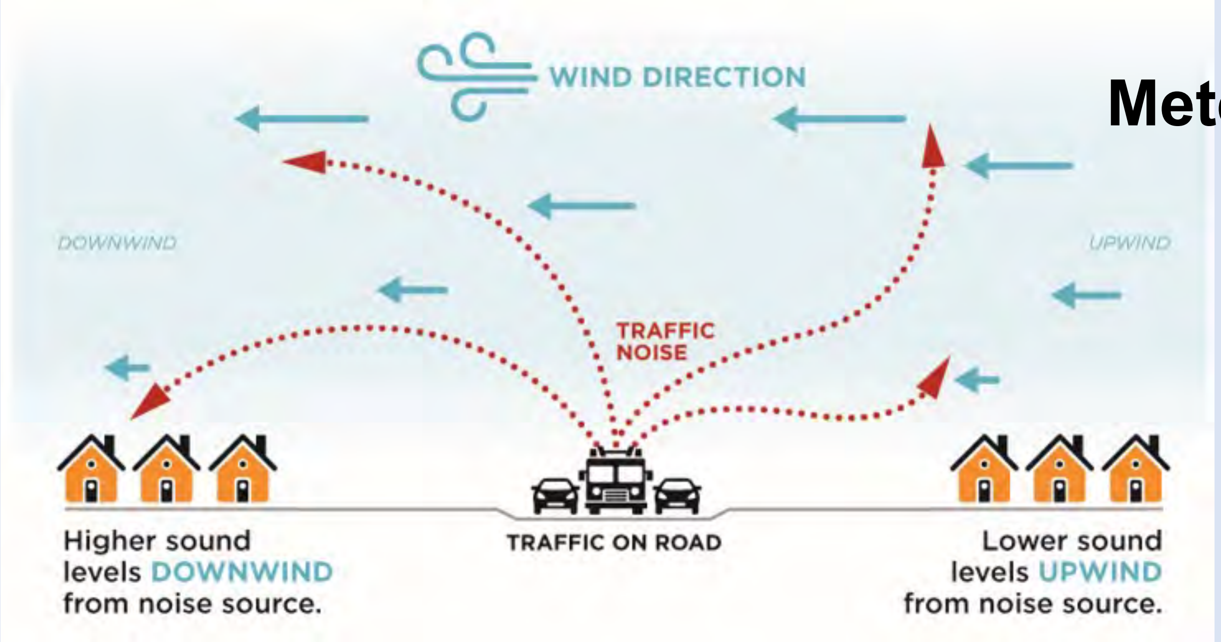
# Transmission Loss

$$TL\ (dB) = 15Log(R_1/R_0)$$

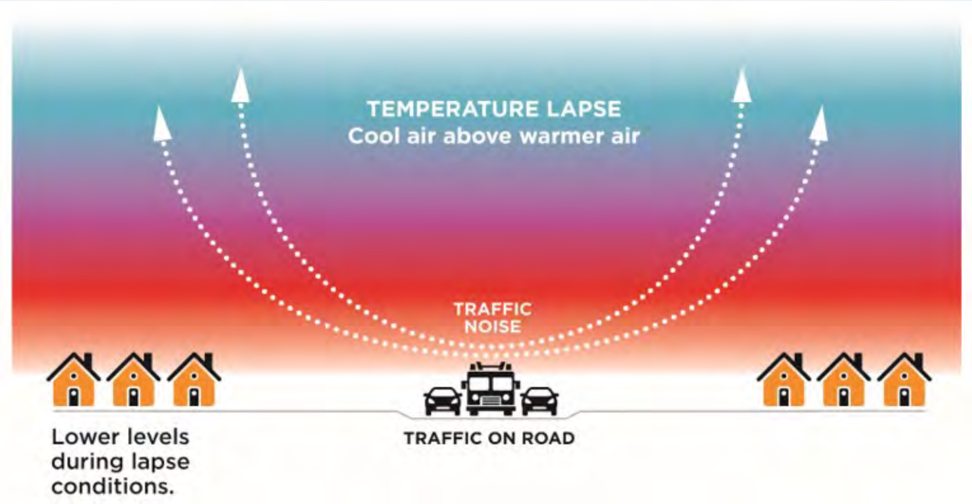


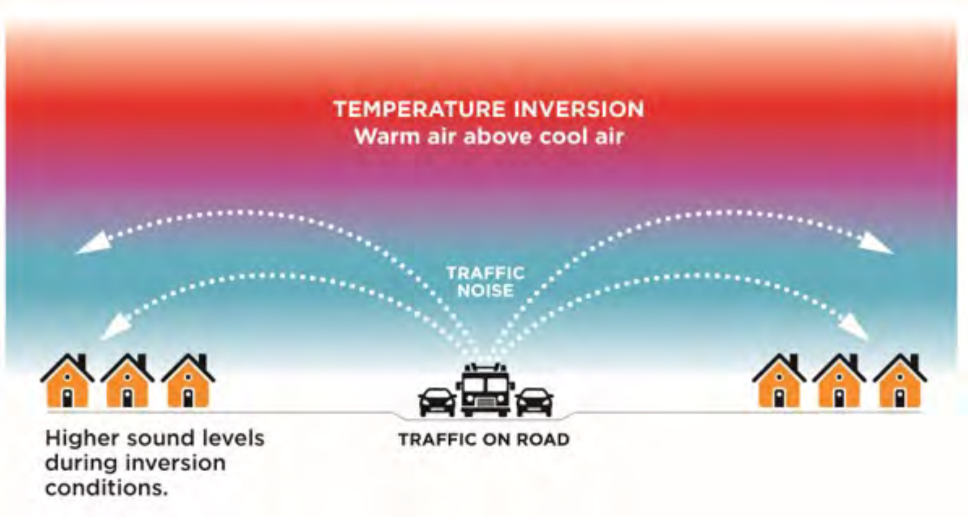

~4.5 dB decrease for each doubling of distance

# Path Influences - Air




Meteorology





Reflective Surfaces


Absorptive Surfaces

# Path Influences - Water

**Reflective Surface & Bottom**
**Direct**
**Reradiating Bottom**
**Winding Streambeds**

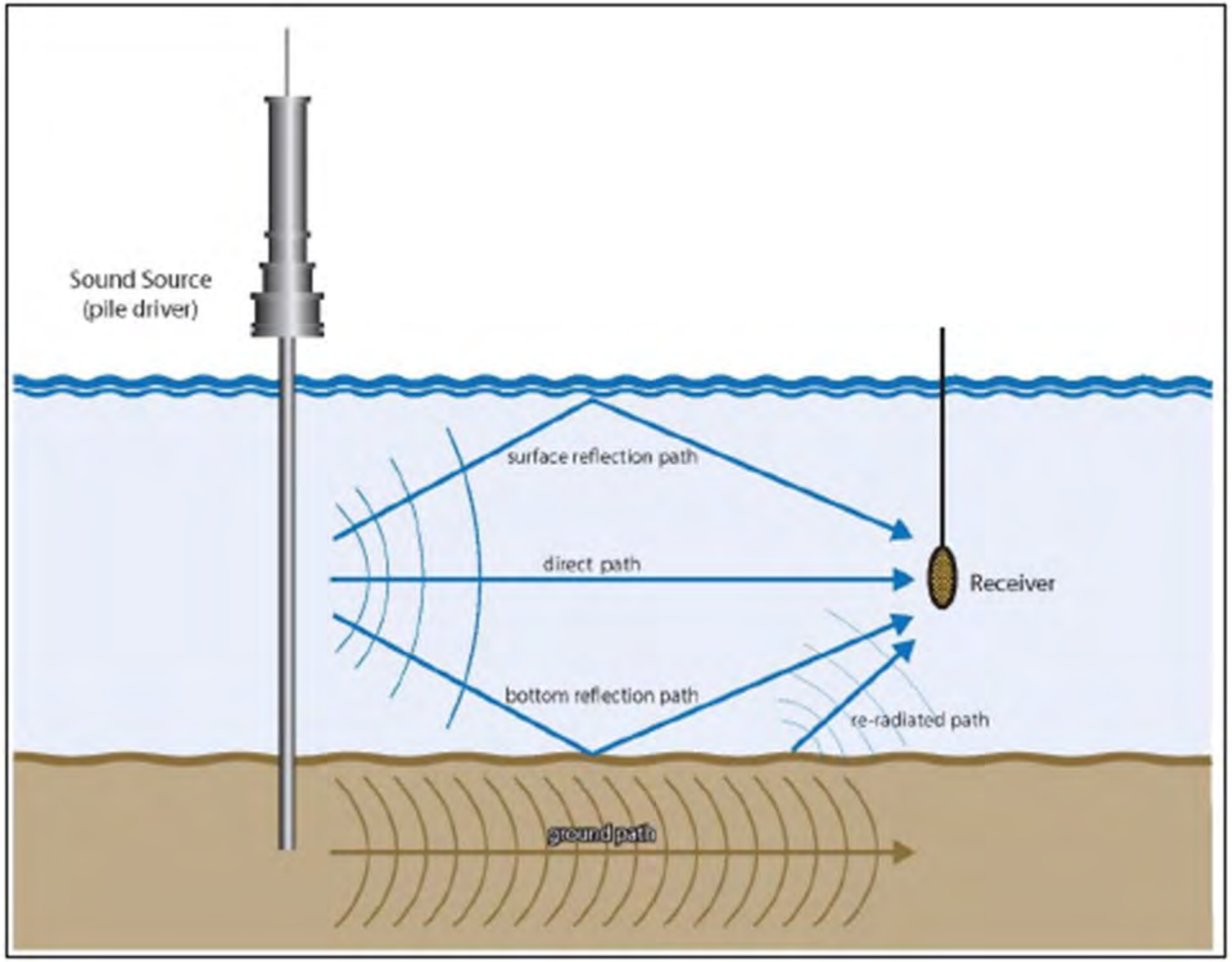



Figure 2-11. Underwater Sound Propagation Paths

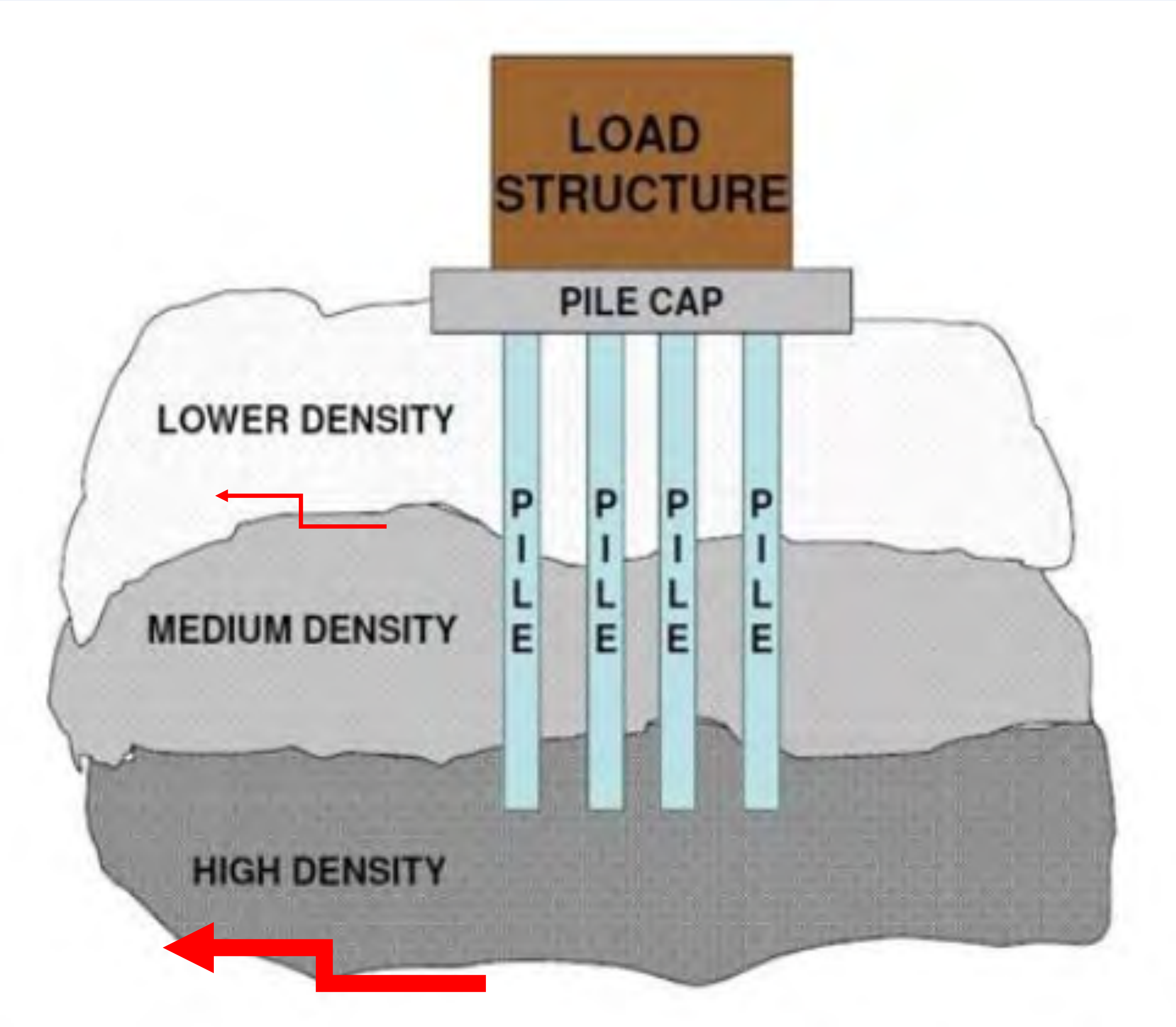
# Path Influence Ground

Ground Stratification

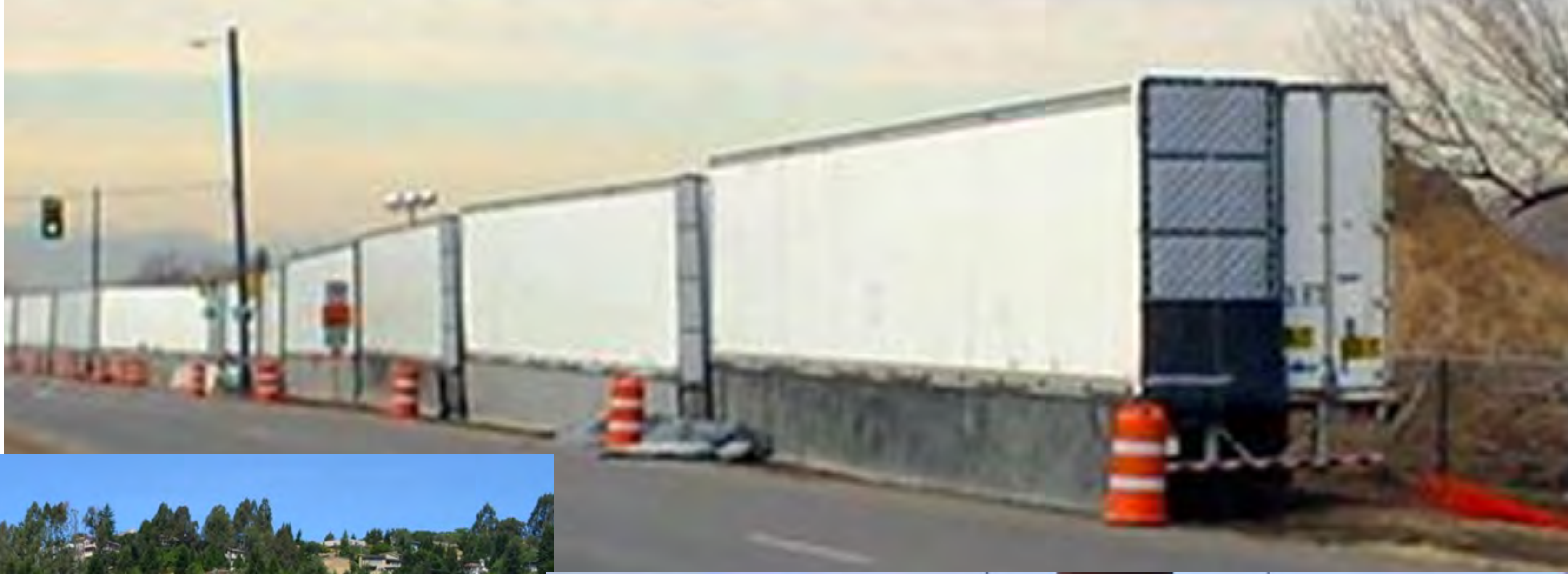
Moisture Content

Loose-Absorptive Material

Dense-Solid-Conductive Material



**Attenuate Noise Energy at the Source or/and Along the Path or/and at the Receptor**



# Check List: Address potential project related noise/vibration impacts

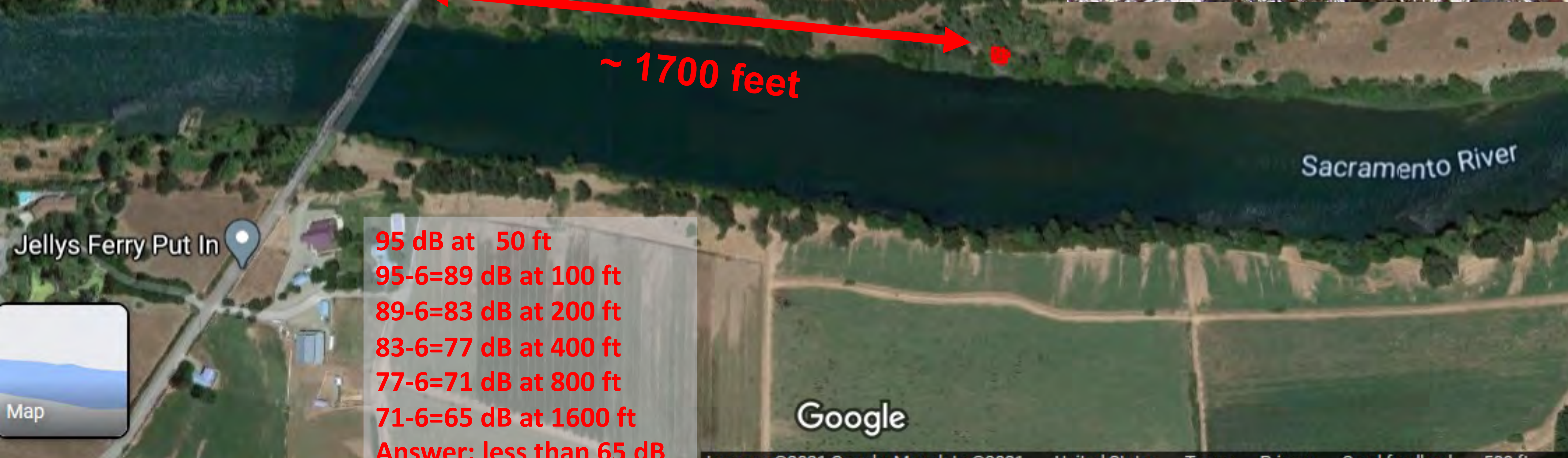
- Characterize the noise/vibration source
- Locate/Position/Characterize sensitive receptors.
- Develop base map with source-path-receiver
- Inventory planned equipment use.
- Determine level of monitoring and/or Control required.

| Equipment Description | $L_{max}$ Noise Limit at 50 feet, dB, Slow | Usage Factor | Impact Device? |
|---|---|---|---|
| Crane (mobile or stationary) | 85 | 16 | No |
| Dozer | 85 | 40 | No |
| Dump truck | 84 | 40 | No |
| Excavator | 85 | 40 | No |
| Flat bed truck | 84 | 40 | No |
| Front end loader | 80 | 40 | No |
| Generator (25 kilovolt-amperes [kVA] or less) | 70 | 50 | No |
| Generator (more than 25 kVA) | 82 | 50 | No |
| Gradall | 85 | 40 | No |
| Grader | 85 | 40 | No |
| Horizontal boring hydraulic jack | 80 | 25 | No |
| Hydra break ram | 90 | 10 | Yes |
| Impact pile driver (diesel or drop) | 95 | 20 | Yes |
| Jackhammer | 85 | 20 | Yes |
| Mounted impact hammer (hoe ram) | 90 | 20 | Yes |
| Paver | 85 | 50 | No |
| Pickup truck | 55 | 40 | No |
| Pneumatic tools | 85 | 50 | No |
| Pumps | 77 | 50 | No |
| Rock drill | 85 | 20 | No |
| Scraper | 85 | 40 | No |
| Slurry plant | 78 | 100 | No |
| Slurry trenching machine | 82 | 50 | No |
| Soil mix drill rig | 80 | 50 | No |
| Tractor | 84 | 40 | No |
| Vacuum street sweeper | 80 | 10 | No |
| Vibratory concrete mixer | 80 | 20 | No |
| Vibratory pile driver | 95 | 20 | No |
| Welder/Torch | 73 | 40 | No |

Source: Federal Highway Administration 2006.

# Construction Equipment Sound Pressure Level at X Distance

# Example Problem




95 dB at 50 ft
95-6=89 dB at 100 ft
89-6=83 dB at 200 ft
83-6=77 dB at 400 ft
77-6=71 dB at 800 ft
71-6=65 dB at 1600 ft
Answer: less than 65 dB

# Abatement at Source

- Noise control at the source is the most sensible approach because it does not limit abatement for a single source-receiver pair, but instead lowers construction noise at all receivers. Caltrans Standard Specifications require all construction equipment to have adequate mufflers and be well maintained. If these specifications are not enough to reduce noise levels to less than the standards and criteria, other options can be used, including one or more of the following.
- Reroute haul routes away from receptors.
- Require modern equipment.
- Plan noisiest operations for times of day (season) when people (wildlife) are less sensitive to noise.
- Plan operations to minimize the use of backup warning devices. Route trucks to minimize back-up alarms
- Set backup warning devices to lowest level without jeopardizing safety.
- Operate equipment at minimum power.
- Use quieter alternate methods or equipment.

Caltrans TeNS: 7.5.3.1

# Abatement in Path

**Options to abate construction noise in the source-to-receiver noise path.**

- **Temporary enclosures around stationary equipment**
- **Temporary barriers, and noise curtains**
- **Permanent noise barriers constructed first**
- **Temporary earth mounds as barriers**
- **Creating buffer zones (distance) between equipment and receptors**
- **Use of existing features/structures as noise barriers.**

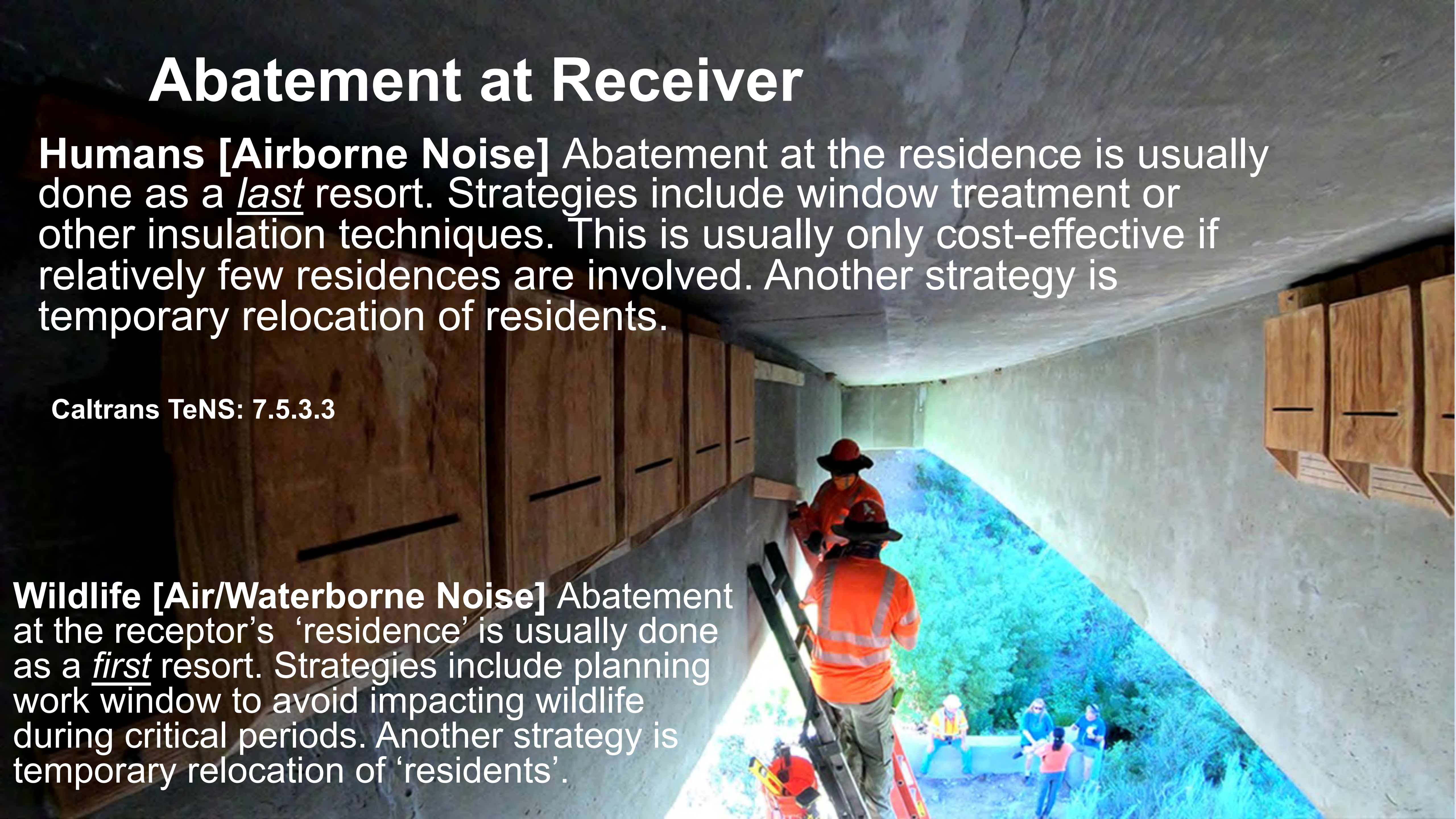
Caltrans TeNS 7.5.3.2

# Abatement at Receiver

**Humans [Airborne Noise]** Abatement at the residence is usually done as a *last* resort. Strategies include window treatment or other insulation techniques. This is usually only cost-effective if relatively few residences are involved. Another strategy is temporary relocation of residents.

**Caltrans TeNS: 7.5.3.3**

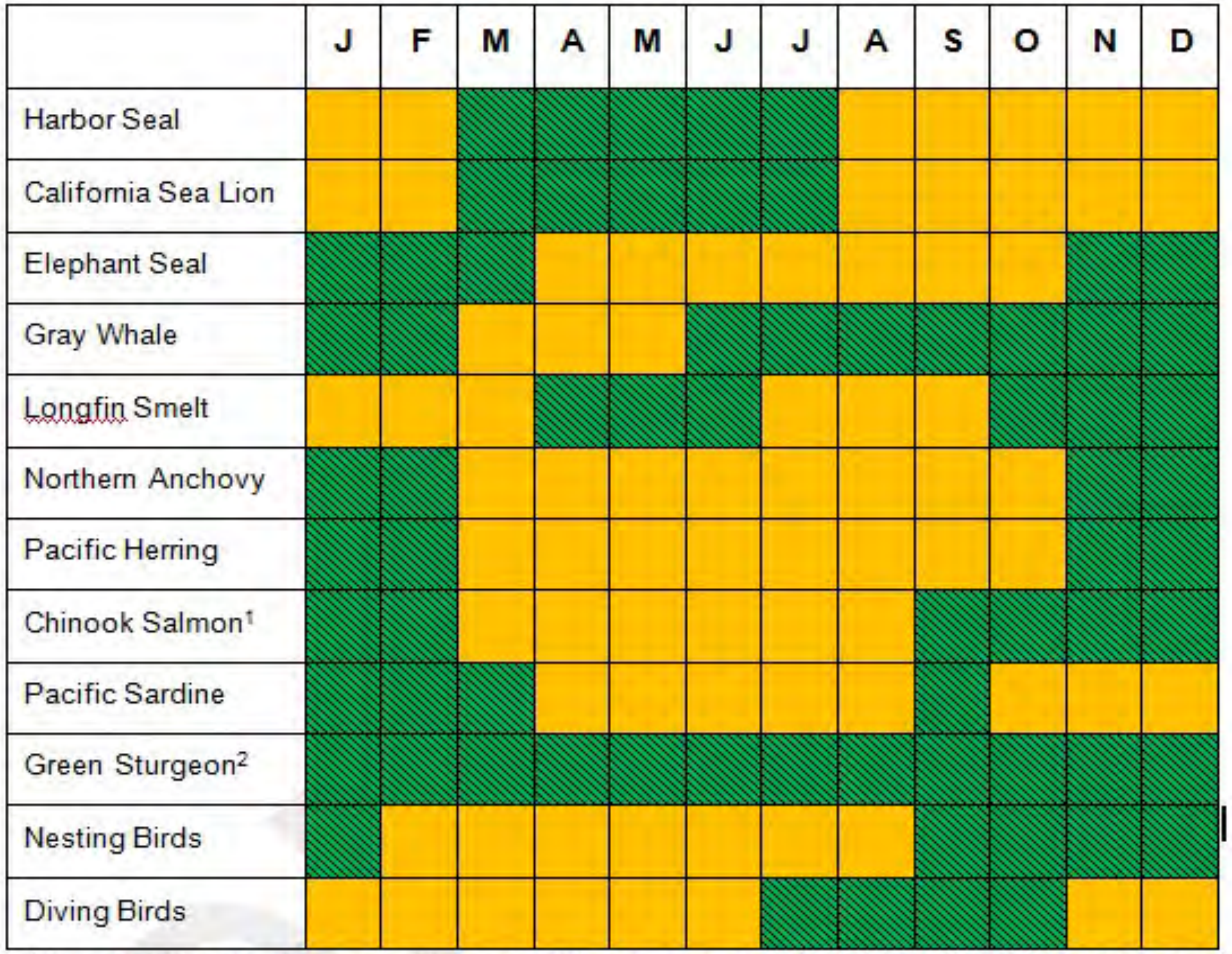
**Wildlife [Air/Waterborne Noise]** Abatement at the receptor's 'residence' is usually done as a *first* resort. Strategies include planning work window to avoid impacting wildlife during critical periods. Another strategy is temporary relocation of 'residents'.



# Species Avoidance and Minimization

## Seasonal work windows

***Green boxes when species are not present or expected at lower densities.**




[1] Juvenile Chinook salmon densities around Pier E3 are low (highest value of 0.25 individuals/10,000 sq. meters in May).

[2] Green sturgeon have potential to occur around Pier E3 year-round, but in very low densities.

# Other Bridge Noise Related Topics

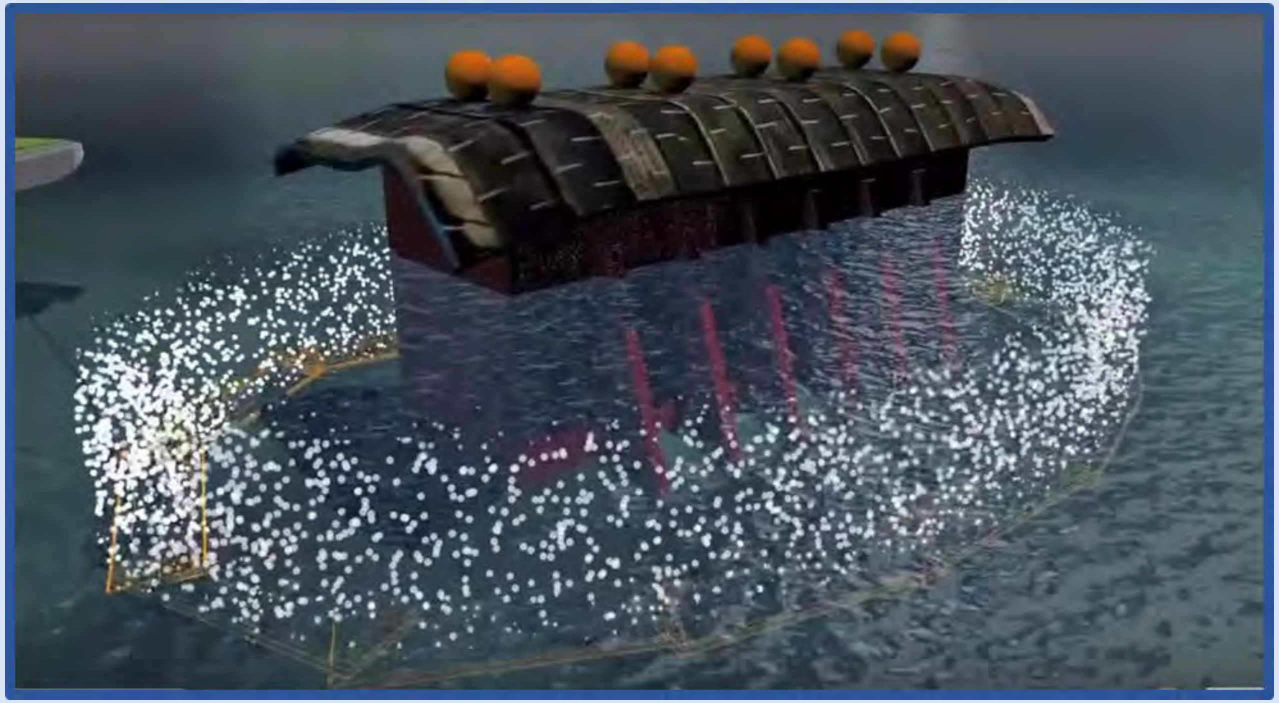
- **Pier Demolition – Deflagration**
- **Operational Traffic Noise**
  - **Decks and tire/pavement noise**
  - **Concrete railing as short sound walls**
  - **Need a low noise expansion joints**

**Earthen Berms are Very Effective, Low-Cost Traffic Noise Barriers**

# Deflagration - Subsonic Demolition

https://www.youtube.com/watch?app=desktop&v=k9EN1IWUDKo

- Potential demolition tool to avoid blasting impacts
- Lowers Source energy levels - Subsonic ‘blast’ energy doesn’t create shock wave
- Works in 90 ft depth of water – quick pier demolition
- Need demonstration project and hydroacoustic measurements to confirm



**Blast Attenuation System – Bubble Curtain**

https://www.youtube.com/watch?v=0Lizk9by-CQ

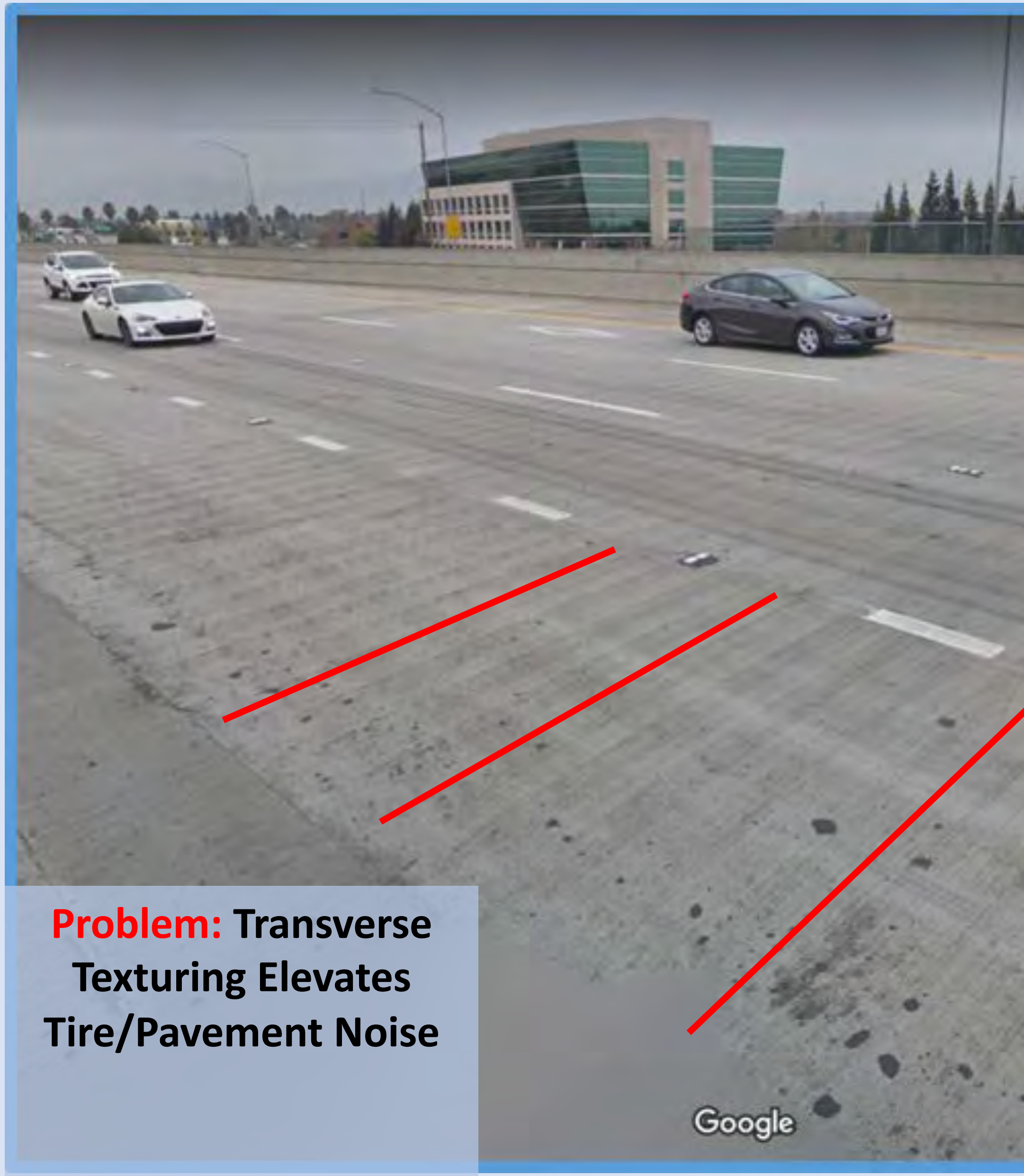
https://www.youtube.com/watch?v=gV-KbyZJthM

# New Bridge Replacement
## Triggers Noise Complaints from Below



**Bridge railing changes from short solid concrete-safety barrier to steel railing**

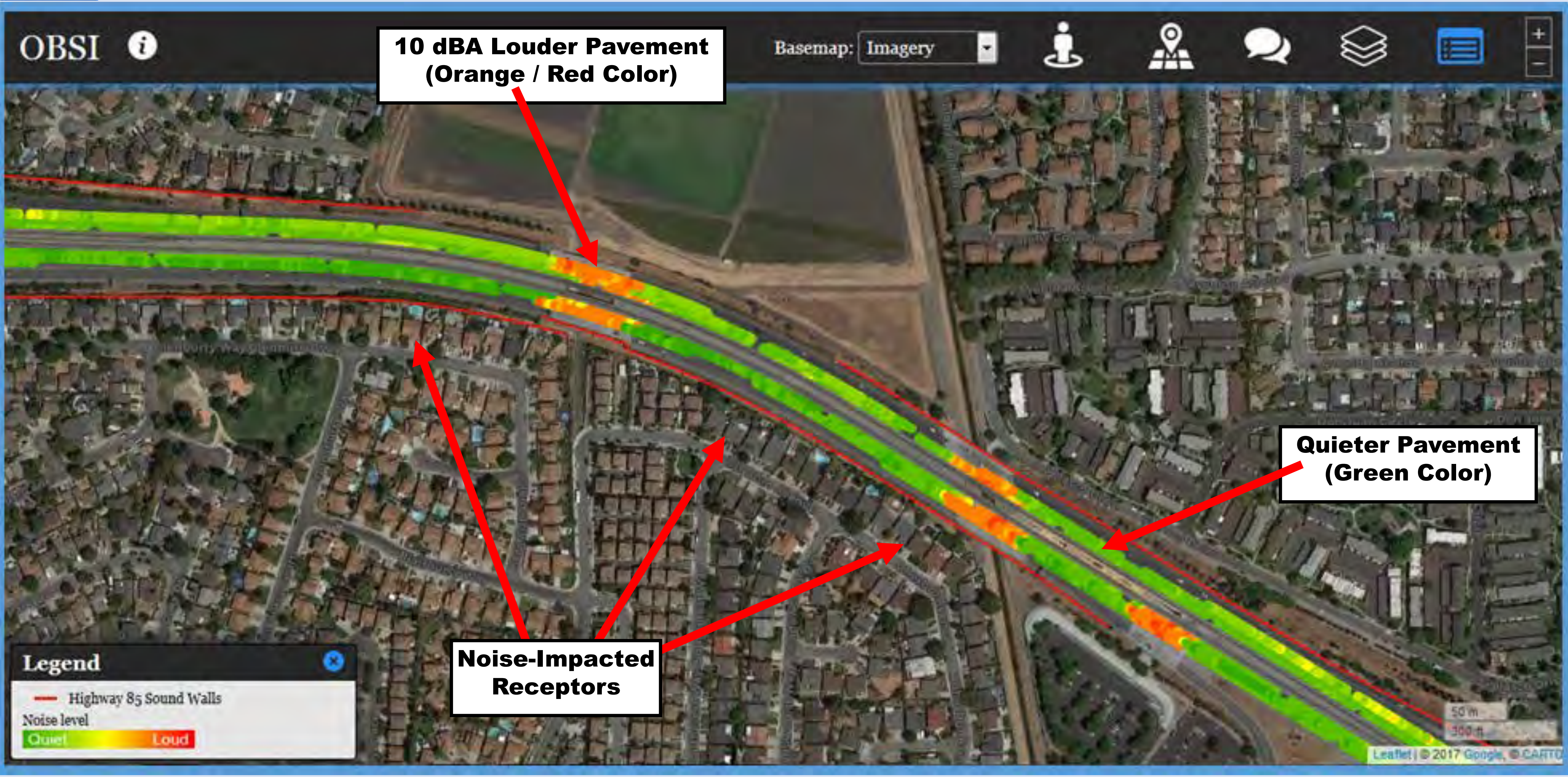
# Legacy - Rigid Pavement Texture



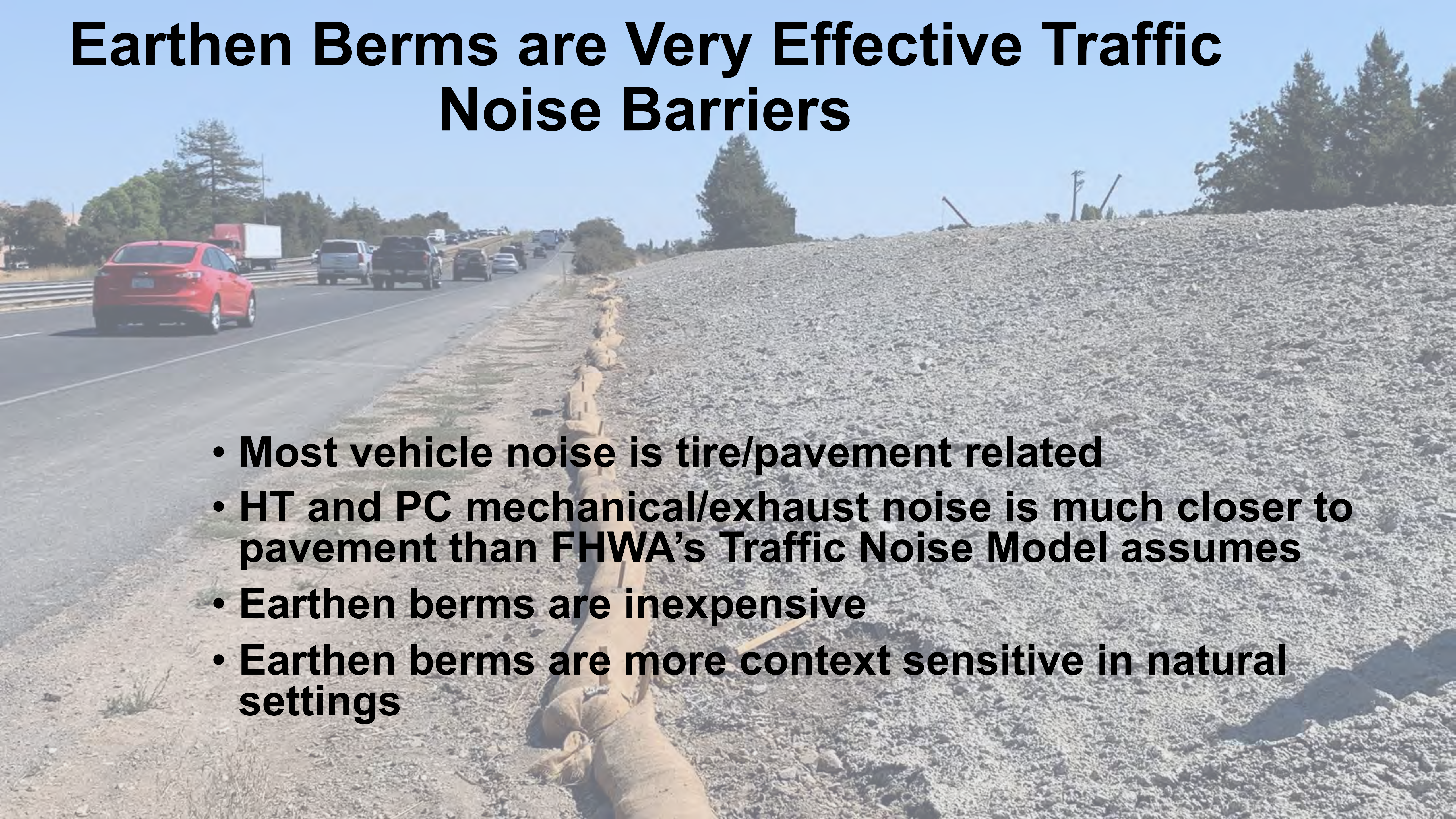

**Problem:** Transverse Texturing Elevates Tire/Pavement Noise

**Solution:** Quieter Pavement Design – Caltrans'
Groove-and-Grind Texture (Longitudinal Texture)
8 – 10 dBA Reduction

# Pavement Acoustics Mapping



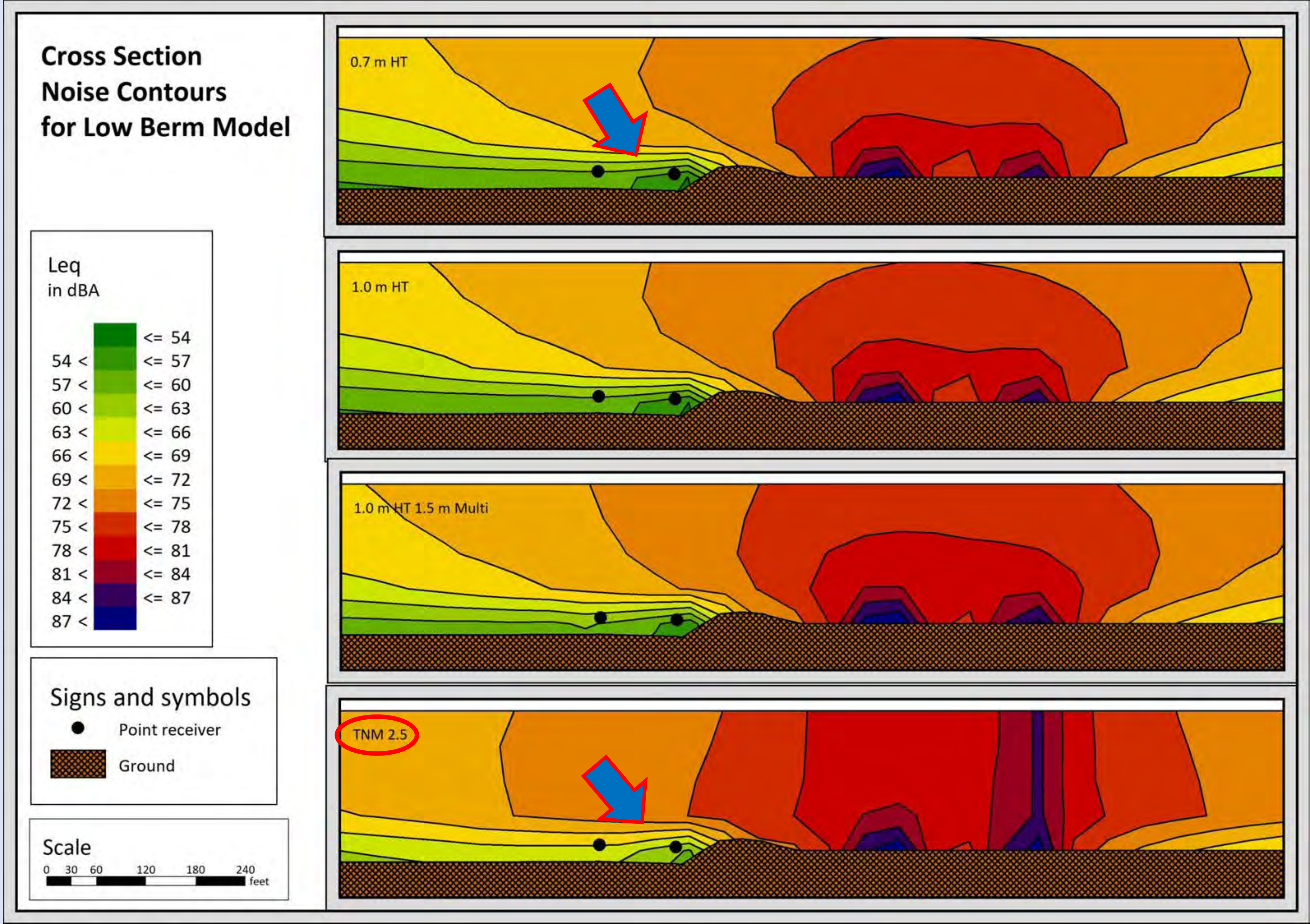
# Earthen Berms are Very Effective Traffic Noise Barriers



- **Most vehicle noise is tire/pavement related**
- **HT and PC mechanical/exhaust noise is much closer to pavement than FHWA's Traffic Noise Model assumes**
- **Earthen berms are inexpensive**
- **Earthen berms are more context sensitive in natural settings**


Nat'l Acad Sci Research found most energy is tire/pavement & 0-3.3 ft above pavement


TNM Places 63% Energy 12 ft Above Pavement



# Summarize

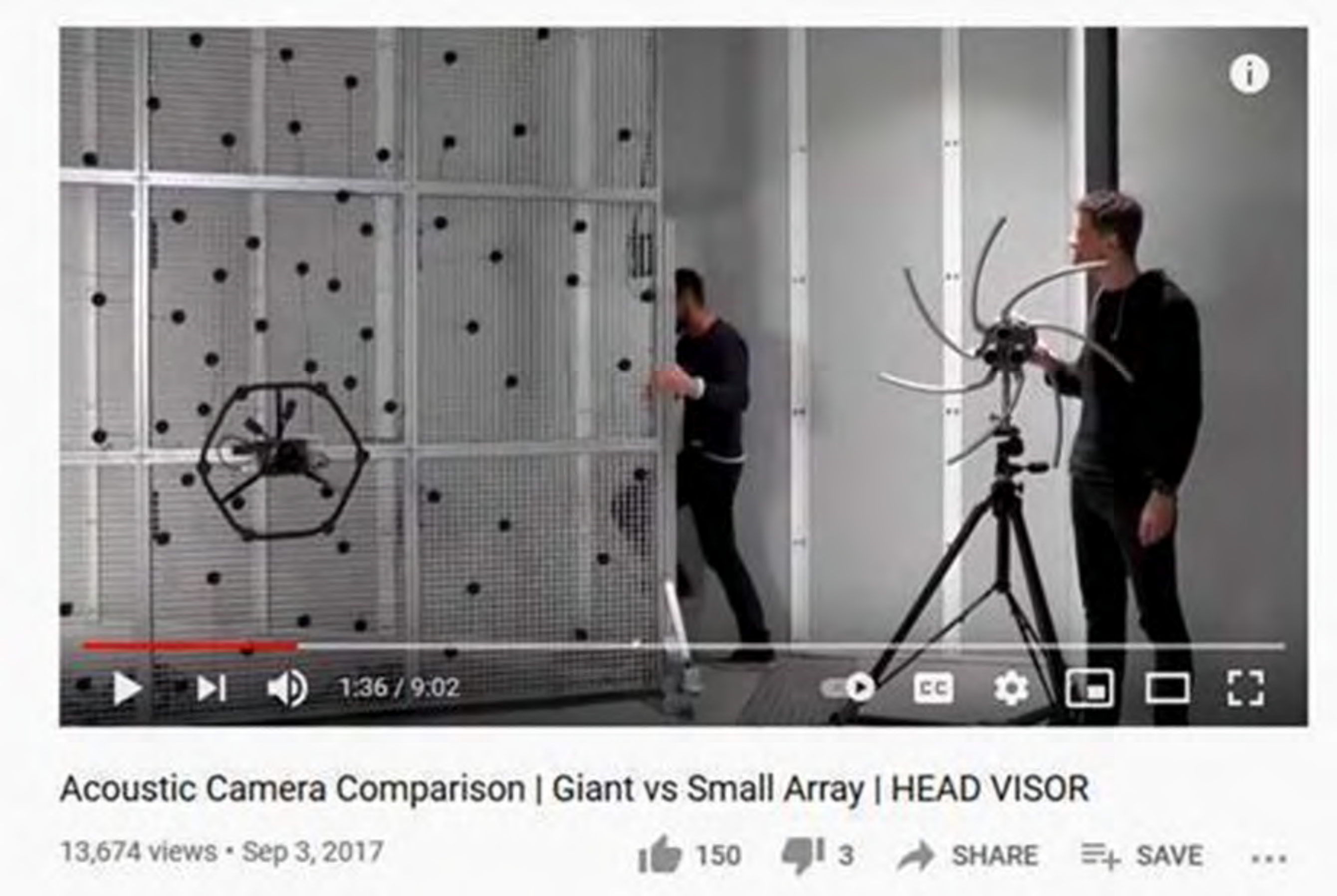
- **Break problem into Source – Path – Receiver components and try to attenuate energy at any component**
- **Blocking or disrupting the Path is the most used approach**
  - **Physical barriers**
  - **Decoupling or disruption Path**
    - **bubble curtains**
    - **annular gaps and coffer dams**
    - **land-based pile driving**
- **More Data**

# Acoustic Beamforming or Acoustic Camera

Like an infrared camera that can ‘see’ thermal heat waves and hot spots, an acoustic camera can be used to ‘see’ sound energy and where it is being generated. The acoustic camera ‘lens’ is an array of interconnected microphones with very clever signal processing. More microphones and a larger diameter mic-array forms a ‘lens’ which produces a more detailed ‘picture’. This 9-minute video shows how an acoustic camera can be used to identify the location and intensity of sound sources.

**Acoustic Camera Comparison | Giant vs Small Array**

https://www.youtube.com/watch?v=r1sqoHXSkEQ




**ALSO:**

**How Hummingbirds Hum**
**New measurement technique unravels what gives hummingbird wings their characteristic sound**
Date: March 16, 2021
https://www.sciencedaily.com/releases/2021/03/210316083758.htm