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Structure Related Noise

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NCHRP Report 791 *Supplemental Guidance on the Application of FHWA's Traffic Noise Model (TNM)*

Prepared for:
National Cooperative Highway Research Program (NCHRP)
Transportation Research Board of The National Academies

The Problem

Structure-Related Noise

- **Structure-Reflected Noise**

- **Structure-Radiated Noise from:**

  Expansion Joints

  Bridge Decks

Structure-Reflected Noise

Structure-Radiated Noise

The Approach

- Compile and/or Develop Modeling Techniques
- Evaluate Modeling Techniques
- Test/Compare Modeling Techniques
- Determine Best Modeling Practices

Modeling Techniques Evaluated

- Technique #1: FHWA TNM modeling of reflected noise by developing image receptors (Also included comparative measurements)
- Technique #2: Using noise measurement data to develop combined structure-related predicted noise levels
- Technique #3: Isolating individual components of structure-radiated noise using noise measurements (Addressed during evaluations of Techniques #1 and #2)

Modeling Technique #1

- Model direct path of noise from the noise source (vehicles on structure) to receptors using FHWA TNM.

- For each affected receptor, calculate noise levels from reflected sources using method described in Reiter/Bowlby paper titled *Using the FHWA Traffic Noise Model (FHWA TNM) to Assess Noise Reflections Off Of the Underside of Elevated Bridge Structures*.

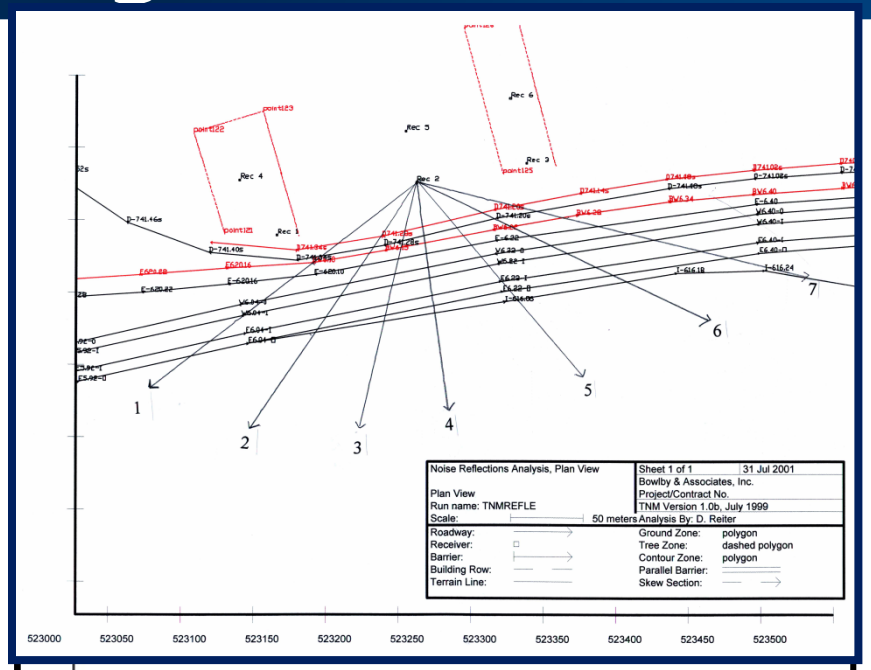
- At each affected receptor, add reflected noise level to the direct noise level generated in base FHWA TNM run to obtain total noise level.

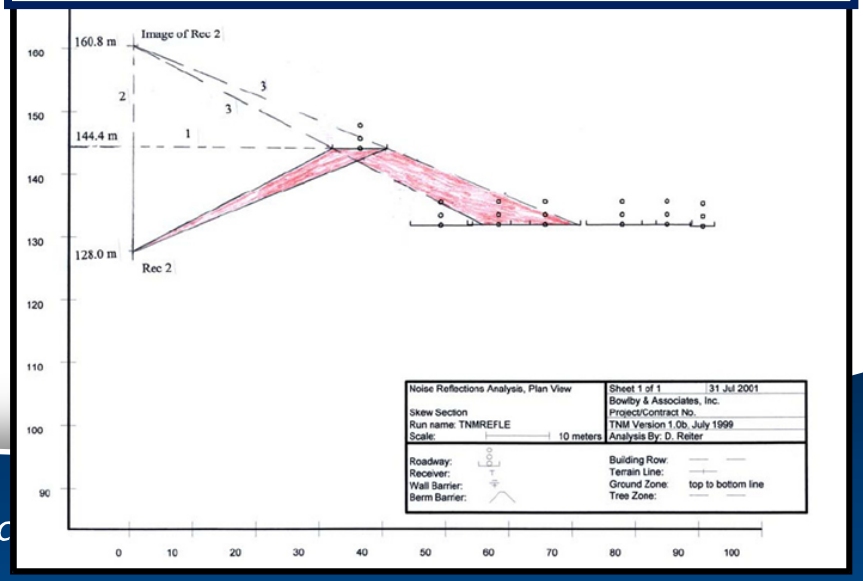
NOTE: This technique only addresses reflected noise and does not account for effects of structure-radiated noise from deck or expansion joints.

To Model "Image" Reflections

- Use TNM skew section views to help identify which sections of roadways and which vehicle types are involved in reflections that reach any particular receptor.

- For any receptor affected by noise reflections, model its associated "reflection-contributing" sources at that receptor's image location using TNM.





Comparison of Modeling Technique #1

- **Reflective and Non-Reflective Sites I-40 Nashville, TN**

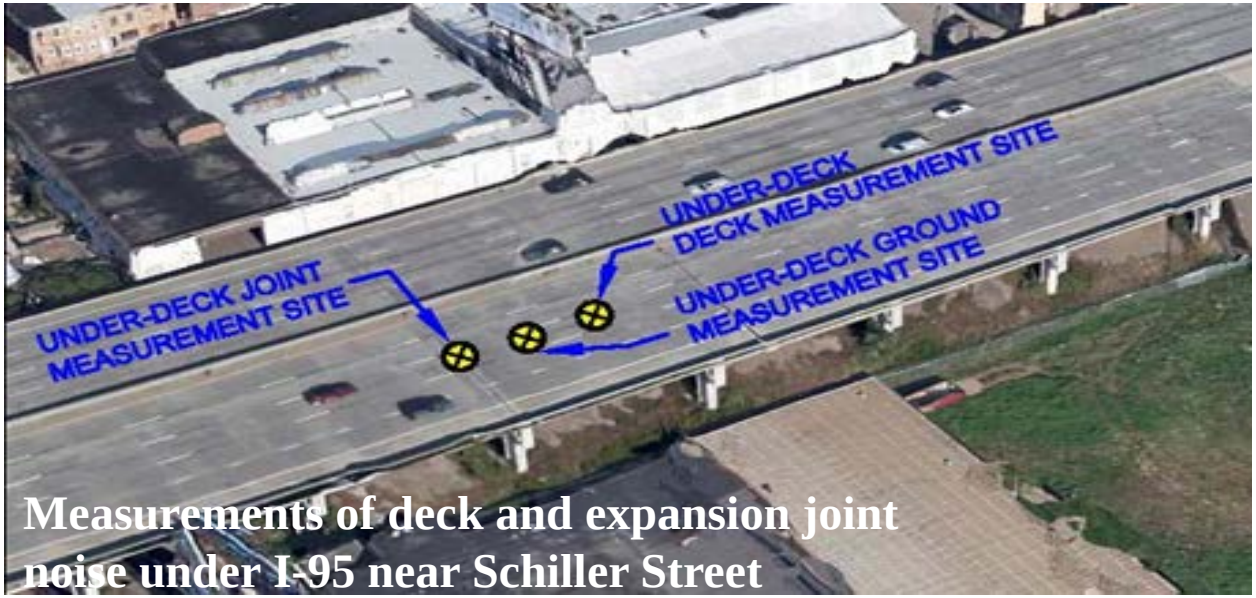
Data from Screening Analysis (from 2001 Reiter/Bowlby Report)			Comparable 2013 Noise Measurement Site Affected by Reflections		Comparable 2013 Noise Measurement Site Not Having Reflections		Estimated Effect of Reflections
Site I.D.	Modeled $L_{eq}(h)$ Noise Level with Barrier and Reflections	Estimated Degradation of Barrier Insertion Loss due to Reflections	Description	Measured L_{eq} Noise Level	Description	Measured L_{eq} in dB(A)	
	dB(A)	dB		dB(A)		dB(A)	dB
1	72	5	Embankment, Elevated Ramp	73	Embankment, No Ramp and Retaining Wall No Ramp Near	65	8
2	74	5	Retaining Wall, Elevated Ramp Far Site	70	Retaining Wall No Ramp Far Site	67	3
3	72	4	Retaining Wall, Elevated Ramp Far Site	70	Retaining Wall, No Ramp Far Site	67	3
	Average >	4.7				Average >	4.7

Average predicted effect of reflected noise using Technique #1 was similar to effects determined via measurements.

Modeling Technique #2

- **Model direct path of noise from the noise source (vehicles on structure) to receptors using FHWA TNM.**
- **Conduct noise measurements of combined structure-related noise levels underneath and adjacent to structure.**
- **Based on noise measurements, develop formulae to model structure-related noise levels at locations adjacent to structure.**
- **Add reflected noise levels to the direct noise levels generated in base FHWA TNM run to obtain total noise levels at adjacent receptors.**

Noise Measurements Underneath I-95

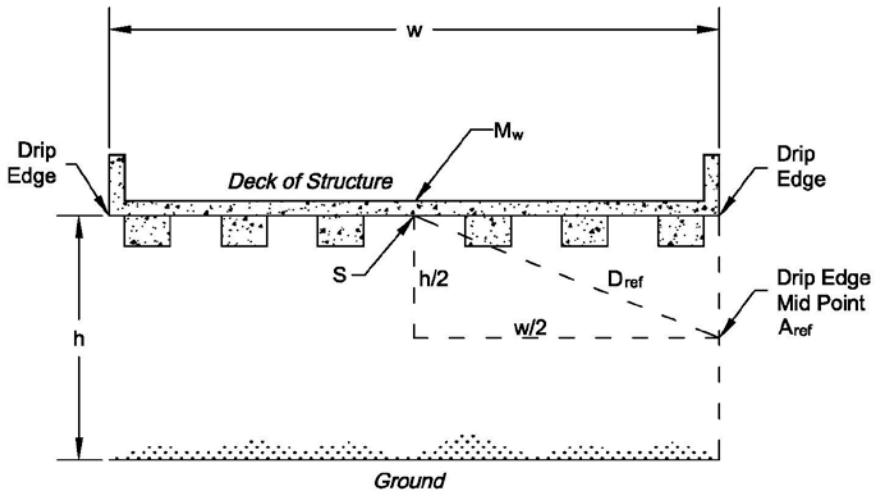


Measurements of deck and expansion joint noise under I-95 near Schiller Street

Little difference in noise levels underneath structure. Therefore, measurement taken at drip edge location would represent combined noise level due to deck and joint noise.

Date	Beginning Time of Measurement	Measured Noise Level, L_{eq} in dB(A)		
		Position 1: Near Joint, within 5 feet of Bottom of Deck	Position 2: Away From Joint, within 5 feet of Bottom of Deck	Position 3: 5 feet Above Ground between Positions 1 and 2
		L_{eq}	L_{eq}	L_{eq}
4/15/2013	3:47pm	63.6	63.2	63.1
	4:08pm	64.4	64.1	64.2
	4:24pm		64.2	64.2

Modeling Assumptions



h = Height of structure, from ground to underside of deck

A_{ref} = Midpoint between ground and underside of deck at drip edge (h/2)

w = Width of structure from drip edge to drip edge

M_w = Midpoint of Structure (w/2)

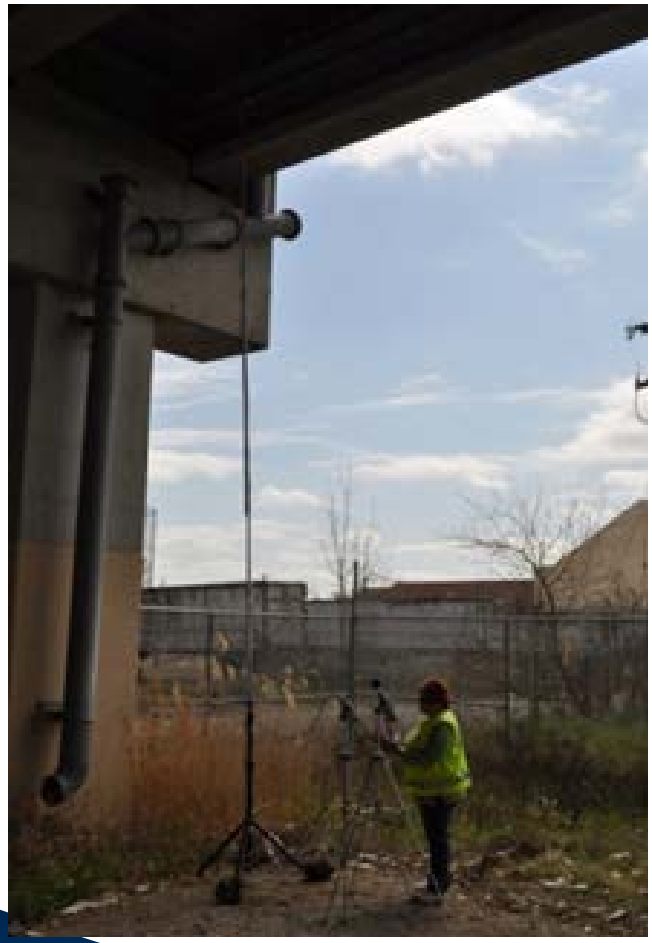
S = Assumed source of structural noise

D_{ref} = Source reference distance calculated by:

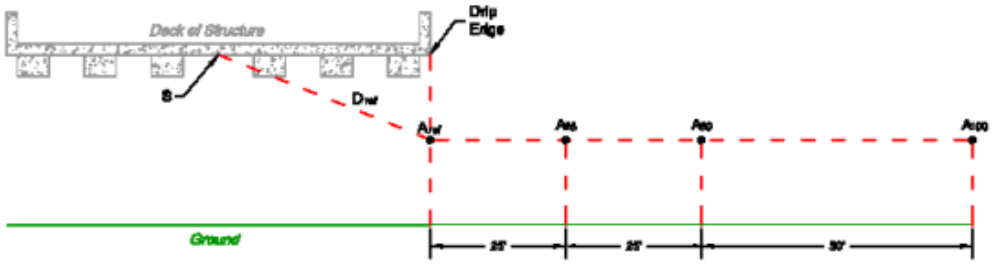
$$(D_{ref})^2 = (w/2)^2 + (h/2)^2$$

Note: Drawing used for graphical purposes only; not to scale.

Noise Measurements at Drip Edge and Adjacent to Structure



Measurements Adjacent to Structure



Formula for Drop Off with Distance

For 3 dB/DD Drop-Off Rate: $L_{Ax} = L_{DE} - 10 \text{ Log}_{10} (D_{AP}/D_{Ref})$

For 4.5 dB/DD Drop-Off Rate: $L_{Ax} = L_{DE} - 15 \text{ Log}_{10} (D_{AP}/D_{Ref})$

For 6 dB/DD Drop-Off Rate: $L_{Ax} = L_{DE} - 20 \text{ Log}_{10} (D_{AP}/D_{Ref})$

Where:

L_{DE} = L_{eq} noise measurement in dB(A) taken at 5 feet above ground under structure drip edge

L_{Ax} = Calculated structure-related noise level at an analysis point A_x, located x feet from the drip edge

D_{AP} = Distance from point S to the analysis point A_x

D_{Ref} = Distance from point S to Point A_{Ref}

Example Worksheet to Estimate Structure-Related Noise at Selected Distances from Structure

Structure-Related Noise Calculation Worksheet

PennDOT I-95 at Schiller Street 4/16/2013 11:11am

Northbound Side at 25 feet and 50 feet

Input Data:

h: Height of structure, from ground to underside of deck	27
A_{ref} : Center point between ground and underside of structure (h/2).	13.5
w: Width of structure	132
M_w: Midpoint of structure (w/2) The underside of the deck at this point is the assumed source of structural noise (S).	66
D_{ref}: Reference distance - from S to A_{ref}	67
Measured Noise Level at Drip Edge, dB(A)	66.0

Set-back Calculations:

Analysis Point	Distance from Drip Edge (ft.)	Distance from S to Analysis Point (ft.)	Measured Noise Level at Drip Edge L_{eq} in dB(A)	Calculated Noise Level, Drop-off Rate = 3.0 dB/DD
A_{ref}	0	67	66.0	
A_{25}	25	92		64.6
A_{50}	50	117		63.6
A_{100}	100	167		62.0
A_{200}	200	267		60.0
A_{400}	400	467		57.6
A_{XXX}		67		66.0

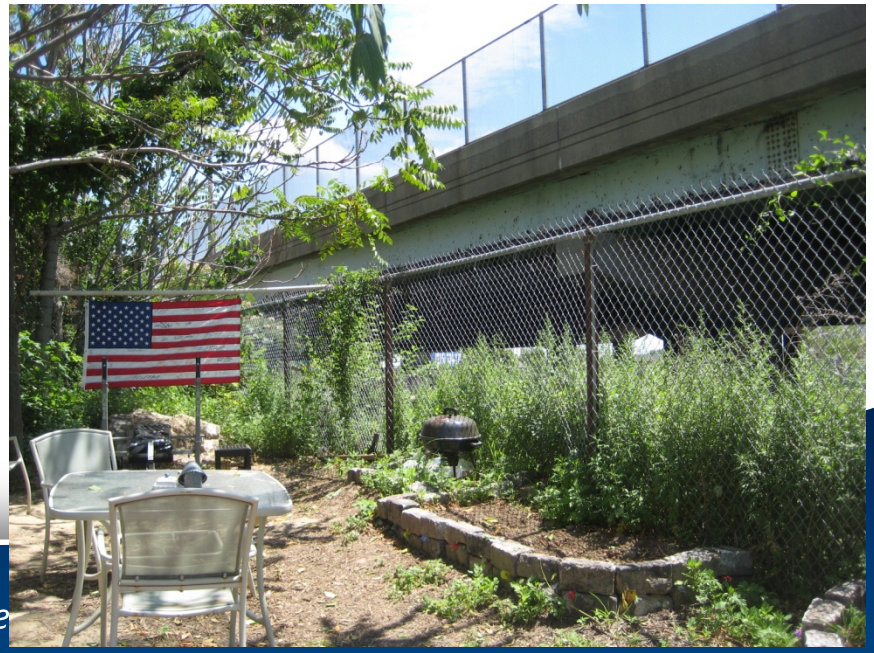
Analysis Point	Distance from Drip Edge (ft.)	Distance from S to Analysis Point (ft.)	Measured Noise Level at Drip Edge L_{eq} in dB(A)	Calculated Noise Level, Drop-off Rate = 4.5 dB/DD
A_{ref}	0	67	66.0	
A_{25}	25	92		63.9
A_{50}	50	117		62.4
A_{100}	100	167		60.1
A_{200}	200	267		57.0
A_{400}	400	467		53.4
A_{XXX}		67		66.0

Analysis Point	Distance from Drip Edge (ft.)	Distance from S to Analysis Point (ft.)	Measured Noise Level at Drip Edge L_{eq} in dB(A)	Calculated Noise Level, Drop-off Rate = 6.0 dB/DD
A_{ref}	0	67	66.0	
A_{25}	25	92		63.3
A_{50}	50	117		61.2
A_{100}	100	167		58.1
A_{200}	200	267		54.0
A_{400}	400	467		49.2
A_{XXX}		67		66.0

Testing of Modeling Technique #2

- **I-95 Sections GIR and AFC Projects in Phila., PA**
  - 5 locations
  - Comparison with EA 2010 and 2012 measurements
- **PA Turnpike Bridge over Susquehanna River**
  - 5 locations
  - Comparison with EA 2010 and 2012 measurements
- **Indiana DOT project**
  - Comparison with Bowlby 2012 measurements
- **Arkansas DOT project**
  - Comparison with Bowlby 2008 measurements

I-95 Projects in Philadelphia, PA



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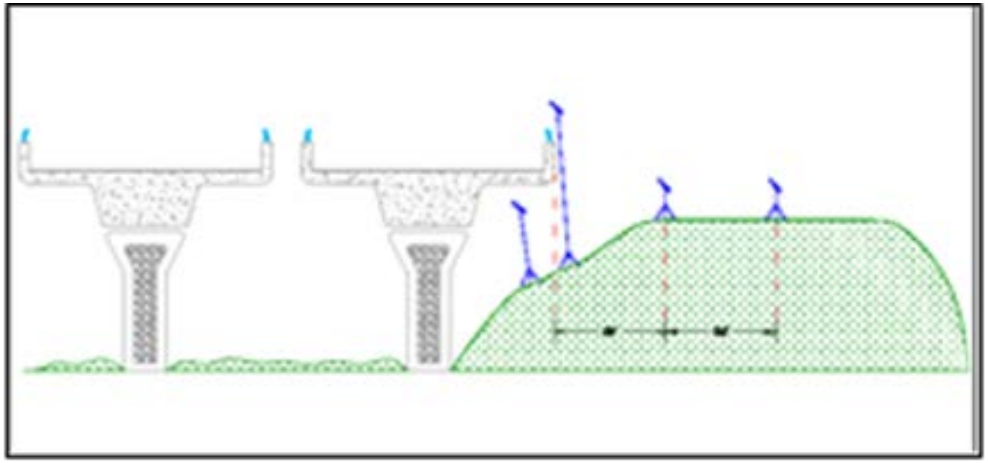
PA Turnpike Bridge over Susquehanna River



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Indiana DOT Project

Arkansas DOT Project

Results of Tests

Data	Measurement Period		Location of Measurement in Relationship to Drip Edge	Measured Leq Noise Level	FHWA TNM Modeled $L_{eq}(h)$ Noise Level due to Highway Traffic Only	Assumed Effect of Structure-Related Noise	Modeled $L_{eq}(h)$ Noise Level Assuming Spreadsheet Value Adjustment for Structure-Related Noise and Assuming Drop-Off Rate of:			Measured Minus Modeled L_{eq} Noise Level Assuming Drop-Off Rate of:		
							3 dB/DD	4.5 dB/DD	6 dB/DD	3 dB/DD	4.5 dB/DD	6 dB/DD
	From	To	feet	dB(A)	dB(A)	dB	dB(A)	dB(A)	dB(A)	dB(A)	dB(A)	dB(A)
I-95 Projects in Philadelphia, PA, 2010 and 2012; Combined deck, joint, and some locations with reflected noise			At Drip Edge	65.5	60.3	5.2						
			25	67.6	61.6	6.0	67.1	66.6	66.2	0.5	1.0	1.5
			50	65.4	65.7	2.5	65.4	67.7	67.1	-0.3	0.5	1.1
			100	66.1	64.4	1.7	67.0	66.3	65.5	-0.9	-0.2	0.3
Pennsylvania Turnpike Bridge over Susquehanna River, 4/17.12; Segmental Concrete (Insignificant deck noise; noise from expansion joint); Noise assumed to drop off from point 3 feet below bottom of deck			Inside of Drip Edge	64.0								
			25	67.4	66.1	1.3	67.4	67.1	66.5	0.0	0.3	0.6
			50	67.7	66.9	0.5	65.0	67.7	67.5	-0.3	0.0	0.2
Indiana DOT Project, 7/14/10; H = 90 feet			At Drip Edge	72.5	57.2	15.6						
			50	69.6	59.1	10.5	70.3	69.2	68.2	-0.7	0.4	1.4
			100	69.1	63.6	5.5	71.0	69.0	69.0	-1.9	-0.5	0.2
			200	67.2	63.9	3.3	70.2	67.9	67.9	-3.0	-1.7	-0.7
Arkansas DOT Project, 2005; H= 17 feet; Noise source drop off from joint			At Drip Edge	79.0	56.4	22.6						
			50	65.7	63.4	5.3	72.1	69.1	66.5	-3.5	-0.4	1.9
			100	67.0	66.0	1.0	71.4	68.3	65.5	-4.4	-1.3	1.2

Best Modeling Practice #1A: FHWA TNM Modeling of Reflected Noise by Developing Image Receptors

Process:

1. Model direct highway noise contributions from all roadways using FHWA TNM.

2. Use Reiter/Bowlby technique to estimate adjustments due to reflections off of the underside of structures.

3. Apply adjustments to obtain structure noise-adjusted predicted noise level.

Applications and Limitations:

- **Since this best modeling practice is solely based on noise modeling, it can be applied to any type of highway project.**
- **Requires detailed geometric and traffic information.**
- **Does not account for different types of superstructures.**
- **Only deals with structure-reflected noise.**

Best Modeling Practice #1B: Noise Measurements at Comparable Sites - With and Without Reflections

Process:

1. Model direct highway noise contributions from all roadways using FHWA TNM.
2. Conduct noise measurements at selected setback locations where reflective noise is believed to be a contributing factor.
3. Conduct simultaneous measurements at "non-reflecting" locations with similar setbacks, traffic, and topography.
4. For each measurement setback distance, calculate the difference between the values for items 2 and 3, above. This is the reflective noise adjustment factor.
5. For each measurement setback distance, apply the item 4 reflected noise adjustment factor to the FHWA TNM value from Item 1 to obtain the structure noise-adjusted predicted noise level.

Applications and Limitations: Same as BMP #1A

Best Modeling Practice #2: Noise Measurement Data Used to Develop Structure-Related Noise Adjustments

Process:

1. **Model direct highway noise contributions from all roadways using FHWA TNM.**
2. **Conduct noise measurements at the drip edge ground level location and at a minimum of two (2) setback distances for purposes validating the FHWA TNM runs and determining the extent of structure-related noise contributions.**
3. **Apply the adjustments from the appropriate Structure-Related Noise Calculation Worksheet to levels at setback locations to determine total modeled noise levels at each setback location.**

Best Modeling Practice #2: Noise Measurement Data Used to Develop Structure-Related Noise Adjustments

Process (cont.):

4. **If expansion joint noise is the predominant structure-related noise source, assume that the noise source emanates from the joint above the measurement point rather than at the midpoint of the structure, and adjust the Worksheet D_{ref} value to be the distance from the drip edge microphone to the bottom of the structure's deck.**
5. **Apply the Worksheet values to FHWA TNM predicted levels for the proposed project using the drop-off rates that best correlate with the measured levels.**

Best Modeling Practice #2: Noise Measurement Data Used to Develop Structure-Related Noise Adjustments

Applications and Limitations:

- **Requires detailed geometric and traffic information.**
- **Most applicable for reconstruction and/or widening projects**
- **Take measurements at structures that resemble the structure type and configuration that nearest replicates that planned for the proposed highway improvement project.**
- **Requires exclusion of extraneous noise sources**
- **Requires sufficient equipment and manpower to perform simultaneous measurements of noise and traffic**
- **Does not account for any reflected noise from other highway noise sources that affects setback locations unless such reflected noise reaches the ground-level drip edge location**