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Using the FHWA Traffic Noise Model (TNM) to Assess Noise Reflections Off Of the Underside of Elevated Bridge Structures

By:

Darlene D. Reiter, Ph.D., P.E.
Bowlby & Associates, Inc.
504 Autumn Springs Court, #11
Franklin, Tennessee 37067
Telephone: (615) 771-3006
Fax: (615) 771-3406
E-Mail: dreiter@bowlbyassociates.com

William Bowlby, Ph.D., P.E.
Bowlby & Associates, Inc.
504 Autumn Springs Court, #11
Franklin, Tennessee 37067
Telephone: (615) 771-3006
Fax: (615) 771-3406
E-Mail: wbowlby@bowlbyassociates.com

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ABSTRACT

Noise reflections off of the underside of elevated bridge structures have the potential to increase traffic noise levels and to degrade the effectiveness of noise barriers at noise-sensitive land uses near proposed highway projects. Assessing the extent to which these reflections will occur requires identifying those roadway segments from which traffic noise will reflect off of the underside of an elevated bridge structure and reach a receiver.

The geometry involved in assessing noise reflections can often be very complex, involving numerous receivers, roadways, and barriers. Such complex geometry makes manual analysis beyond the scope of most noise analyses. As a result, assessing noise reflections off of the underside of elevated bridge structures has traditionally been difficult and time-intensive.

This paper presents a procedure that can be used to assess noise reflections off of the underside of elevated bridge structures using features of the Federal Highway Administration's (FHWA) Traffic Noise Model (TNM). (1) The procedure is intended to provide a screening level of analysis to determine whether or not noise reflections off of the underside of elevated bridge structures will increase traffic noise levels or degrade noise barrier performance in noise-sensitive areas. If the results of the noise reflections analysis using this screening level procedure are found to increase traffic noise levels or degrade barrier effectiveness, more detailed analysis may be warranted.

PROBLEM DESCRIPTION

Noise reflections off of the underside of elevated bridge structures have the potential to increase traffic noise levels and to degrade the effectiveness of noise barriers at noise-sensitive land uses near proposed highway projects.

Traffic noise levels are expressed in terms of the hourly, A-weighted equivalent sound level in decibels (dB, often written as dBA). The "A-weighted" refers to the amplification or attenuation of the different frequencies of the sound (subjectively, the pitch) to correspond to the way the human ear "hears" these frequencies. Because most environmental noise fluctuates from moment to moment, it is standard practice to condense data into a single level called the A-weighted equivalent sound level (L_{Aeq}). The L_{Aeq} is the value of a steady sound level that would contain the same amount of sound energy as the actual time-varying sound evaluated over the same time period. The L_{Aeq} is a measure that relates well to the impact of noise on people. For traffic noise assessment purposes, L_{Aeq} is typically evaluated over the worst one-hour period (typically, the loudest hour, which often is the design hour) during the design year of the project and is written as L_{Aeq1h} and referred to as the one-hour equivalent sound level throughout this report.

Assessing whether noise reflections off of the underside of an elevated bridge structure will occur requires the analyst to identify the often numerous paths of noise reflection from a roadway off of the underside of an elevated bridge structure to a particular receiver. Identifying the reflection paths can be difficult since the vertical geometry between a particular receiver and roadway changes continuously along the roadway. As a result, a reflections path between a receiver and a roadway might only exist for a small section of a roadway and the analyst must identify this section.

Once the roadway segments from which reflections will originate are identified for each receiver, the analyst must predict the one-hour equivalent sound level at each receiver from those roadway segments. This one-hour equivalent sound level is called the noise reflection contribution throughout this report. This noise reflection contribution must then be added to the TNM predicted "no barrier" and "with barrier" one-hour equivalent sound levels to determine total one-hour equivalent sound levels at each receiver. The problem is further complicated if multiple roadways and/or multiple receivers exist and if a noise barrier is being considered for the area. As a result, analysis of noise reflections off of the underside of elevated bridge structures has traditionally been difficult and time-intensive since a computerized method for assessing these reflections has not been developed.

NOISE REFLECTIONS ANALYSIS PROCEDURE

The greatest challenge in assessing noise reflections off of the underside of elevated bridge structures is generating sketches or plots of the vertical geometry between the receiver, the elevated bridge structure, and the roadways that can be used to identify the reflection paths between each roadway and each receiver.

TNM includes a feature that allows the analyst to generate views of "skew" sections that can be used for this purpose. These "skew views" show the spatial relationships in the vertical plane cut across TNM objects such as receivers, roadways, and barriers. Generating skew views is fairly simple, and numerous skew views can be generated in a short time period.

The analysis procedure described herein involves generating, printing, and analyzing numerous skew views for each modeled receiver, or a selected subset of modeled receivers, in an area. These skew views are then used to identify the roadways from which traffic noise will reflect off of the underside of the elevated bridge structure and reach the receiver.

To activate a skew view in TNM, the analyst must click on the TNM Plan View to make it the active window. The analyst then selects the "View" menu bar from the main TNM tool bar, then selects "New View," then selects "Skew Section." A new type of mouse cursor appears that looks like a saw. The analyst then clicks on the "Snap" icon on the main TNM tool bar. The "Snap" icon shows an arrow on a grid. Enabling the "Snap" function ensures that the receiver being analyzed will appear in the skew view. The analyst then clicks on the receiver being analyzed. The analyst then needs to then disable the "Snap" function by clicking again on the "Snap" icon. The icon color should turn from white (active) to gray (inactive). The analyst then locates a point on the other side of the TNM roadways and clicks. After this click, a skew view will appear that shows the vertical relationship between the receiver and roadways as well as any other TNM objects such as barriers and building rows.

Figure 1 shows a skew view that includes the receiver, an elevated bridge structure, and several roadways.

The analyst should note that when a roadway is modeled "on structure," TNM erroneously shows terrain lines extending from the elevated bridge structure to surrounding TNM objects. These terrain lines do not exist since the structure is elevated. When generating and analyzing the skew views, it is helpful to hide these terrain lines. In order to accomplish this, the analyst selects the "View" menu bar from the main TNM tool bar, then selects "Show/Hide." A dialogue bow will appear. In the "Show Objects" column, the analyst must click on the box for terrain lines then click the "OK" icon. The terrain lines will disappear.

Figure 2 shows the locations of several residences located near a proposed elevated bridge structure for a ramp. This area is the subject of the Case Study presented in the following report section. Figure 3 then shows the TNM plan view of the noise model for this area and shows the locations of the analyzed skew views for "Rec 2" in the file. Figure 4 shows skew view number 4 from Figure 3 and Figure 5 shows skew view number 6 from Figure 3.

Before generating the skew views, the analyst should ensure that the elevated bridge structure is modeled properly for the analysis. When modeling the elevated roadway in the base TNM model to predict one-hour equivalent sound levels without consideration of noise reflections, the roadway would typically be modeled in the center of the travel lane(s). The roadway width would then be set to properly model the location of the outside edge of bridge structure. As a result, the modeled width may not match the actual width of the bridge structure for the roadway. For example, the pavement width for an elevated one-lane roadway that has a single 3.6 m travel lane, a 3 m outside shoulder, and a 1.2 inside shoulder would be 7.9 m. However, the modeled pavement width in TNM would be determined by taking the distance from the modeled roadway to the edge of the outside shoulder and multiplying this number by a factor of two. In this case the TNM roadway width would be set to 9.6 m, or 4.8 m (half of the 3.6 travel lane plus the 3 m outside shoulder) multiplied by two.

As a result, the modeled roadway may need to be shifted in the TNM file to the centerline of the bridge structure and the TNM roadway width should be set to the actual width of the bridge structure.

The elevation of the roadway should also be lowered to represent the elevation of the underside of the bridge structure and not the elevation of the travel lanes.

Once a set of skew views has been generated and printed for each analysis receiver, each skew view must be analyzed to determine if noise reflections off of the underside of the elevated bridge structure will reach the receiver. This step involves the following steps:

1. Draw a horizontal line from the elevated structure to a point above the modeled receiver;
2. Locate an "image" receiver above the horizontal line drawn in Step 1; and,
3. Draw lines from the "image" receiver through each of the outside edges of the elevated bridge structure until these lines intersect the ground. The horizontal distance between the two lines indicate the location from where noise reflections would originate if a noise source were located there. As a result, if a roadway (s) is located in this area, then traffic noise from this roadway section would be expected to reflect off of the underside of the elevated bridge structure and reach the receiver.

These steps are indicated by the numbers 1 through 3 on the skew views in Figures 4 and 5.

As shown in Figure 4, traffic noise from two of the roadways will reflect off of the underside of the elevated bridge structure and reach "Rec 2" while traffic noise from the other four roadways will not.

Similarly, the skew view shown in Figure 5 indicates that traffic noise from the outside roadway will reflect off of the underside of the elevated bridge structure and reach "Rec 2" while traffic noise from the other roadways will not.

As indicated in the skew views in Figures 4 and 5, TNM has three separate source heights for automobiles, medium trucks, and heavy trucks. The reflection path may include only one or two of these source heights for a particular roadway segments. For this procedure, it is assumed that noise from all three vehicle types on an identified roadway segment would reflect off of the underside of the elevated bridge structure if the reflection path intersected the pavement.

The number of skew views required may vary from receiver to receiver depending on the geometry involved. Once a first set of skew views is analyzed as described below, the analyst may generate and analyze additional skew views to gain a better understanding of the extents of the roadway segments from which noise reflections will originate.

Once all of the skew views have been analyzed, the analyst can identify those roadway segments from which traffic noise will reflect off of the underside of the elevated bridge structure and reach the receiver.

The analyst then creates a separate TNM file for each receiver with only those roadway segments from which reflections will originate and the “image” receiver. The image receiver is located at the image height above the ground shown in Figures 4 and 5. Modeling the image receiver ensures hard site propagation from the traffic on the roadways to the receiver.

The TNM plan view shown in Figure 6 shows the segments from which noise reflections will originate and reach “Rec 2.”

TNM is then run to determine the noise reflection contribution at each of the analysis receivers. This TNM predicted noise reflection contribution is then added to the predicted “no barrier” one-hour equivalent sound levels at each receiver to determine actual “no barrier” one-hour equivalent sound levels.

If a barrier is proposed for the area, the analysis needs to be repeated for the “with barrier” condition if the noise barrier will block some or all of the noise reflections. If the barrier will not block the noise reflections, then the reflection noise contributions for the “with barrier” case are the same as for the “no barrier” case.

For the “with barrier” case, the noise reflection contribution is added to the “with barrier” one-hour equivalent sound level without consideration of reflections to arrive at the actual “with barrier” one-hour equivalent sound level. The barrier IL with reflections is then recalculated by subtracting the “with barrier” one-hour equivalent sound level with reflections from the “no barrier” one-hour equivalent sound level with reflections. The barrier degradation in terms of reduction in IL can then be determined by subtracting the predicted barrier IL without reflections from the predicted barrier IL with reflections.

As stated above, this procedure is intended for use at a screening level of analysis. Each site will vary and may have unique considerations including the type of bridge structure (box beam, steel girder, etc.), multiple reflection paths, superelevated bridge structures, and stop-and-go traffic conditions. In these cases, the analyst may opt to complete a more detailed analysis.

CASE STUDY

The Tennessee Department of Transportation (TDOT) will be widening Interstate 40 (I-40) and reconstructing the interchange of I-40 and Robertson Avenue/Briley Parkway in Nashville. The proposed interchange will include four levels and will involve the construction of several elevated bridge structures for ramps near noise-sensitive land uses adjacent to the interchange.

A detailed noise analysis was completed for the project using TNM. The design year was 2019 and several areas of noise-sensitive land use were identified and analyzed.

The review of the locations of the elevated bridge structures for the noise analysis indicated that mainline traffic noise might reflect off of the underside of some of the elevated bridge structures and reach residences in these areas.

Of particular concern was the elevated bridge structure for the ramp from eastbound I-40 to northbound Briley Parkway. The bridge structure is located approximately midway between the I-40 mainline and several first-row residences on the north side of I-40 as shown in Figure 1. I-40 is on a slight fill through this area and the ramp structure is elevated 12 to 20 meters (m) above the residences. I-40 is approximately 50 m wide through this area so reflection paths from some of the roadways to the receivers were expected.

The procedure described above was used to assess whether noise reflections would increase “no barrier” one-hour equivalent sound levels for these residences. Additionally, a noise barrier for this area was determined to be both feasible and reasonable in accordance with TDOT’s Noise Policy (2) without consideration of the noise reflections. As a result, the effect of the noise reflections on the barrier’s effectiveness was also completed.

Table 1 presents the analysis results.

As shown in Table 1, predicted “no barrier” one-hour equivalent sound levels at the three modeled first-row receivers without consideration of the noise reflections off of the underside of the elevated bridge structure are in the

72 to 76 dBA range. The predicted "no barrier" one-hour equivalent sound levels at the three modeled second-row receivers are in the 69 to 72 dBA range.

The term insertion loss (IL) is generally used to describe the reduction in one-hour equivalent sound level at a location after a noise barrier is constructed. For example, if the one-hour equivalent sound level at a residence before a barrier is constructed is 75 dBA and the one-hour equivalent sound level after a barrier constructed is 65 dBA, then the insertion loss would be 10 dB.

The noise barrier for the area was designed to provide 7 to 10 dB insertion loss (IL) for impacted first-row receivers resulting in "with barrier" one-hour equivalent sound levels around 65 dBA. The barrier was 4.5 to 5.0 m high.

In this case, the noise barrier would not block the reflection paths from the roadways to the receivers. As a result, the noise reflection contribution shown in column five of Table 1 is the same for the "no barrier" and "with barrier" cases. As indicated, the noise reflection contribution is between approximately 71 and 73 dBA for the modeled first-row receivers and between 69 and 73 dBA for the modeled second-row receivers. These contributions equal or exceed the predicted "no barrier" one-hour equivalent sound level at one of the three first-row receivers and at all three second-row receivers. These higher noise contributions result from hard site propagation of the noise reflections off of the underside of the elevated bridge structure. Additionally, I-40 is on fill through the area. As a result, the edge-of-pavement of I-40 provides shielding for the modeled receivers from I-40 traffic noise. The noise reflected off of the underside of the bridge structure, however, is not shielded.

This noise refection contribution in column five of Table 1 was added to the "no barrier" and "with barrier" one-hour equivalent sound levels in columns two and three to arrive at the "no barrier" and "with barrier" one-hour equivalent sound levels with reflections in columns six and seven.

The "with barrier" one-hour equivalent sound levels at modeled first-row receivers are increased by 6 dB to 9 dB resulting in "with barrier" one-hour equivalent sound levels of 72 to 74 dB. As noted above, the barrier would not block the reflection path from the roadways to the receivers. Thus, the noise reduction provided by the mainline barrier is reduced from a range of 7 to 10 dB for first-row receivers down to a range of 2 to 5 dB.

As indicated in Table 1, the "with barrier" one-hour equivalent sound levels at modeled second-row receivers are also increased by 6 to 9 dB resulting in "with barrier" one-hour equivalent sound levels of approximately 70 to 74 dB. Thus, the noise reduction provided by the mainline barrier is reduced from a range of 5 to 7 dB for second-row receivers down to approximately 2 dB.

TDOT's Noise Policy requires a minimum 7 dB IL for the barrier to acoustically feasible. As a result, the barrier was determined not to be feasible unless the effectiveness of the mainline barrier can be maintained by application of some type of absorptive treatment to the underside of the elevated bridge structure in this area.

Treatment possibilities might include use of an absorptive coating on the underside of the bridge structure or the use of absorptive baffles that would hang beneath the structure. However, any type of treatment will have implications for bridge inspection, maintenance, and safety. The cost of such treatments would also need to be considered.

Noise reflections analyses were also completed for three other areas adjacent to the proposed interchange using this procedure. The results for these areas indicated that noise reflections would not be significant and the performance of the barriers for these areas would not be degraded.

CONCLUSIONS

The noise reflections analysis procedure presented herein can be used to quickly and efficiently assess noise reflections off of the undersides of elevated bridge structures for projects that involve the construction of elevated bridge structures near noise-sensitive land uses.

The procedure is intended to provide a screening level of analysis to determine whether or not noise reflections off of the underside of elevated bridge structures will increase one-hour equivalent sound levels or degrade noise barrier performance in noise-sensitive areas. If the results of the noise reflections analysis using this screening level procedure are found to increase one-hour equivalent sound levels or degrade barrier effectiveness, more detailed analysis may be warranted.

REFERENCES

1. *Traffic Noise Model (TNM) Version 1.0b*, Federal Highway Administration, July, 1999.
2. *Tennessee Department of Transportation Guidelines on Highway Traffic Noise Abatement*

LIST OF TABLES AND FIGURES

TABLE 1 Noise Reflections Analysis Results

Receiver	Analysis Results without Reflections			Reflections Contribution (dBA)	Analysis Results with Reflections			Insertion Loss Degradation (dB)
	"No Barrier" L_{Aeq1h} (dB)	"With Barrier" L_{Aeq1h} (dB)	Insertion Loss (dB)		"No Barrier" L_{Aeq1h} (dB)	"With Barrier" L_{Aeq1h} (dB)	Insertion Loss (dB)	
First-Row Receivers								
Rec 1	76	66	10	71	77	72	5	-5
Rec 2	72	65	7	73	76	74	2	-5
Rec 3	72	65	7	71	75	72	3	-4
Second-Row Receivers								
Rec 4	72	65	7	73	76	74	2	-5
Rec 5	70	64	6	71	73	71	2	-4
Rec 6	69	64	5	69	72	70	2	-3

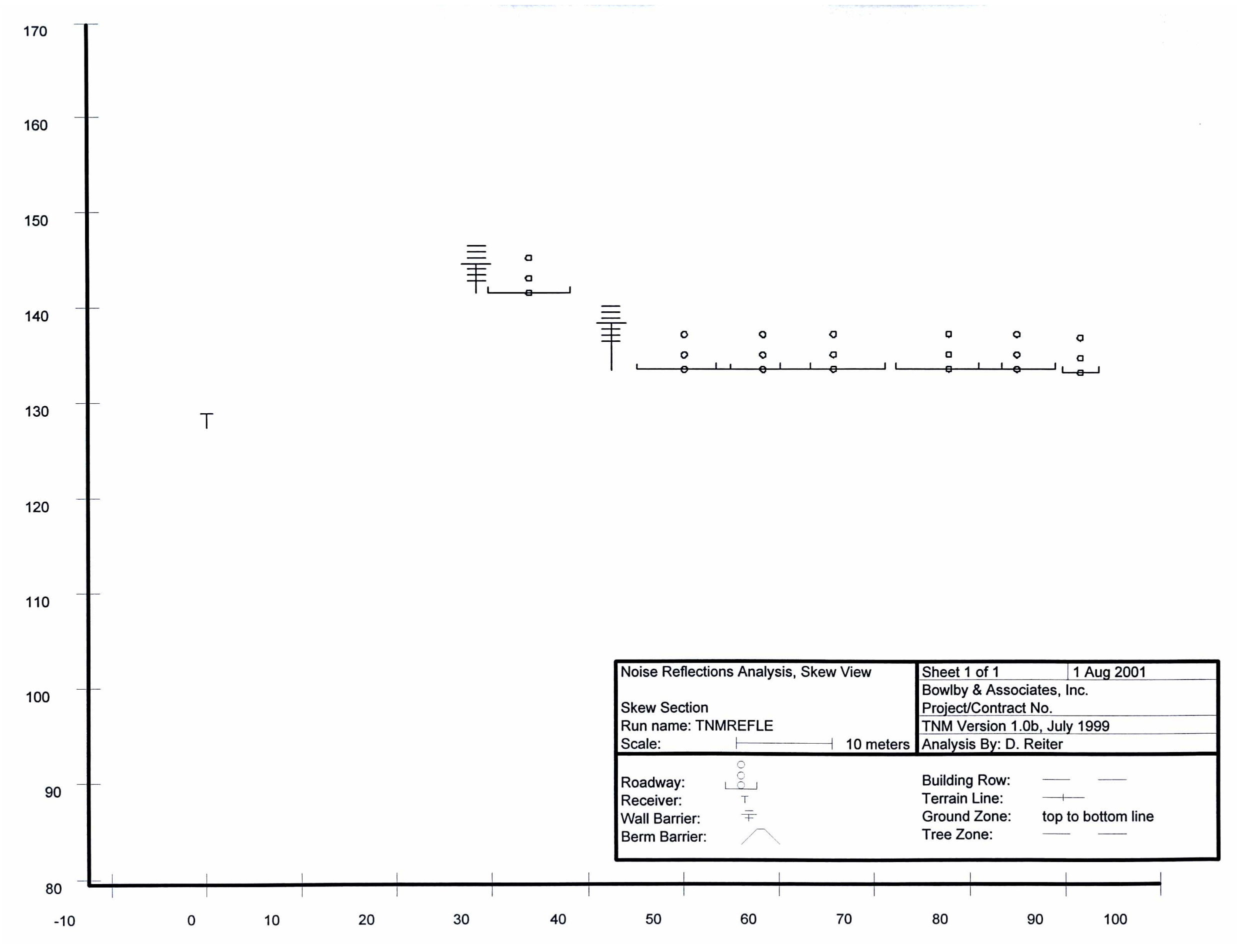

FIGURE 1 Sample TNM skew view.

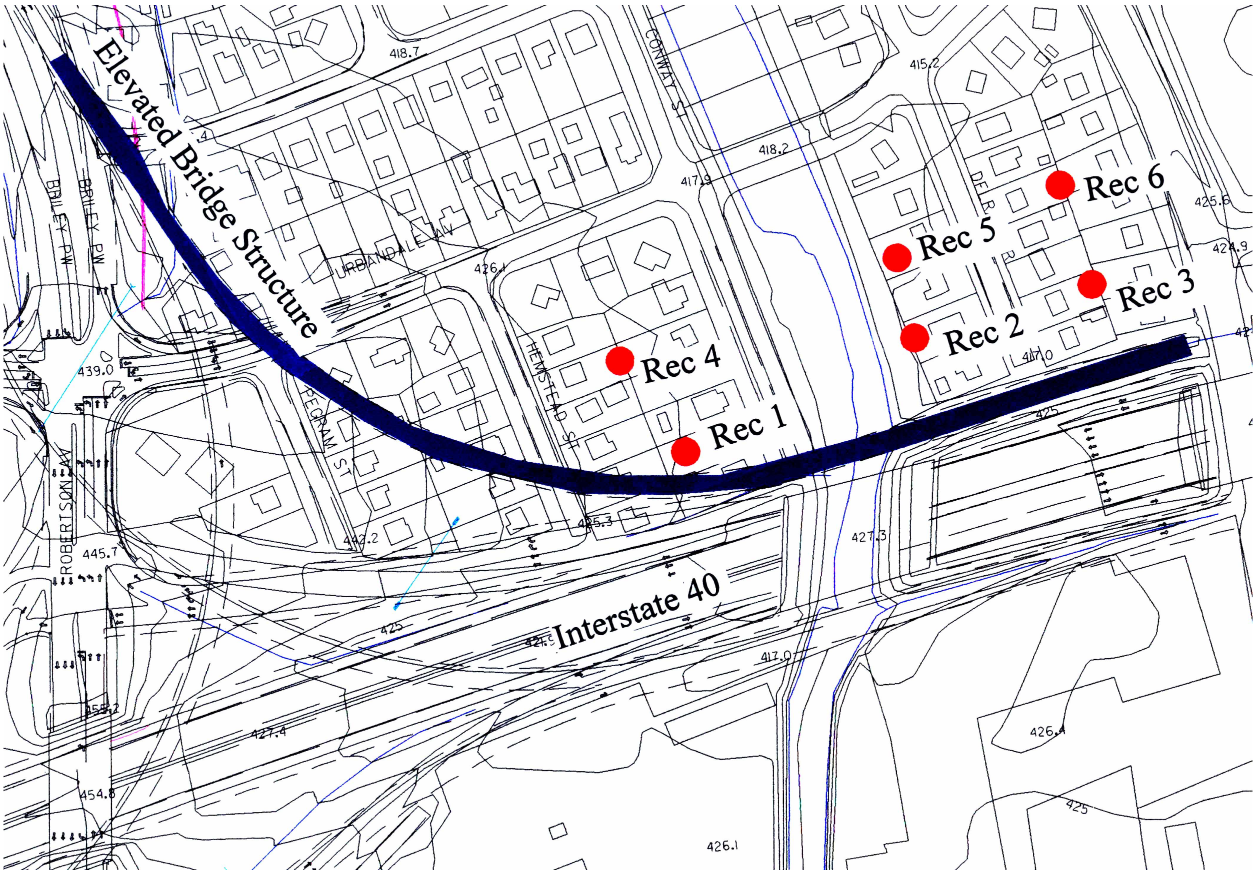

FIGURE 2 Residences located near a proposed elevated bridge structure.

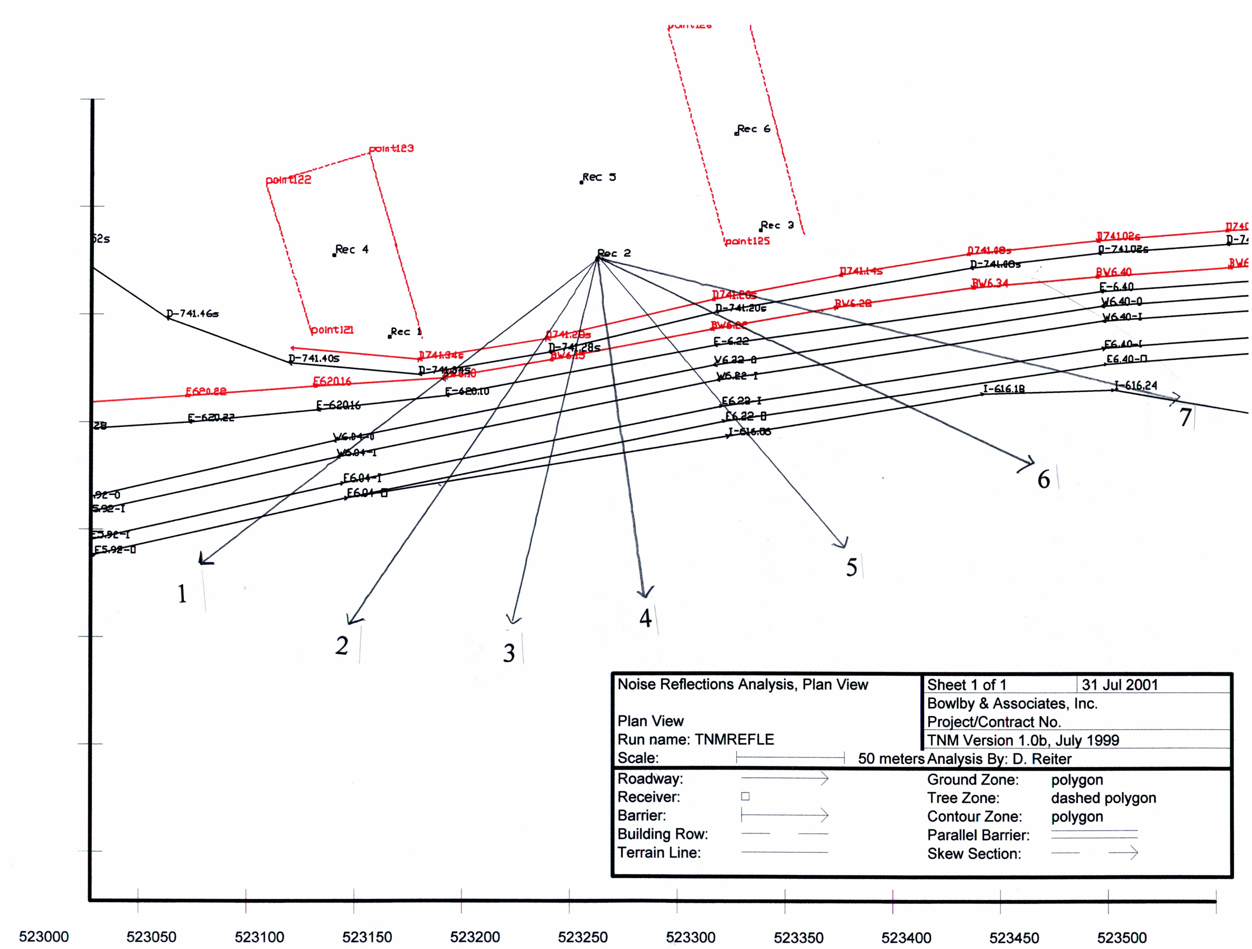

FIGURE 3 TNM skew view locations for a sample receiver in a TNM plan view.

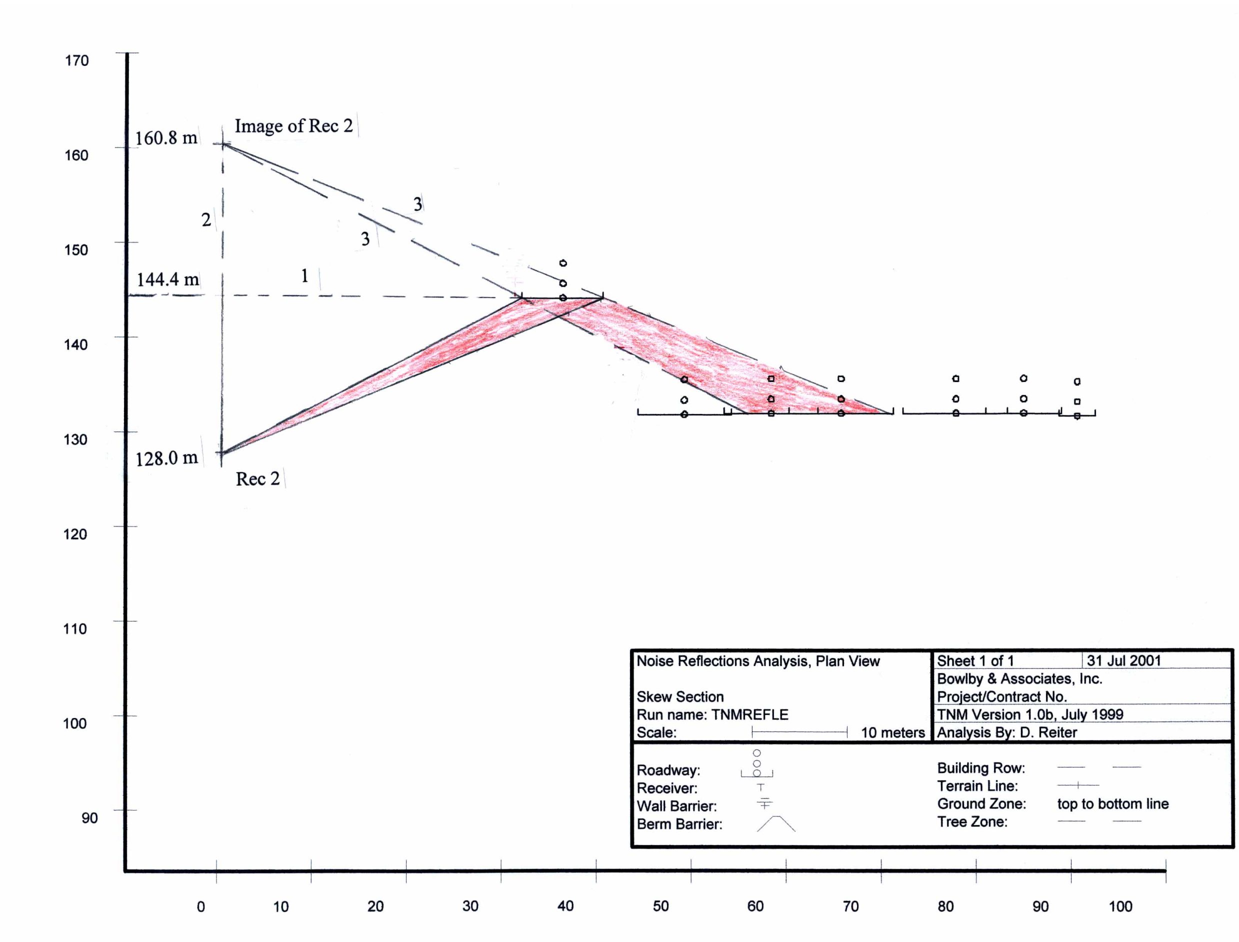

FIGURE 4 TNM skew view number 4 for Rec 2.

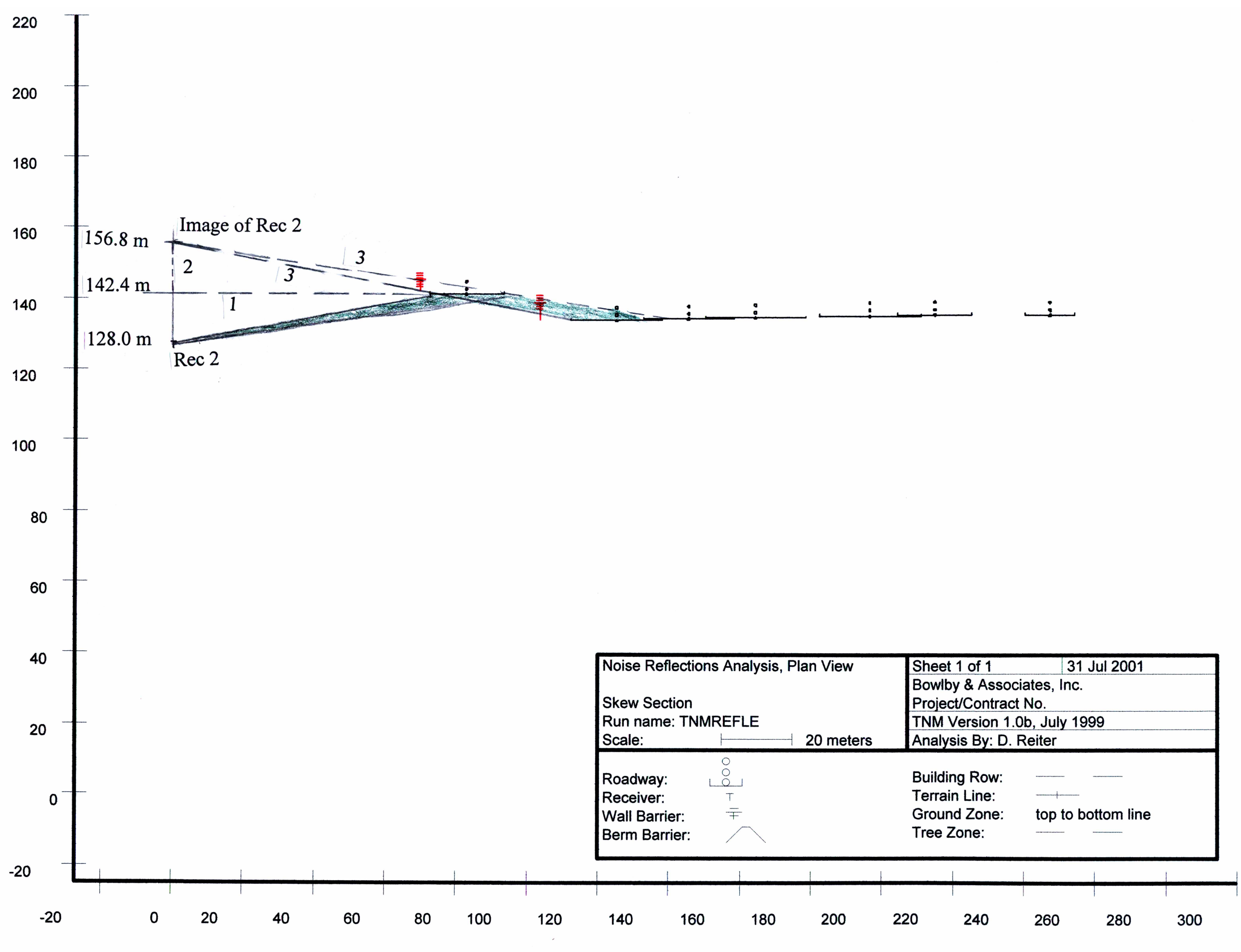

FIGURE 5 TNM skew view number 6 for Rec 2.

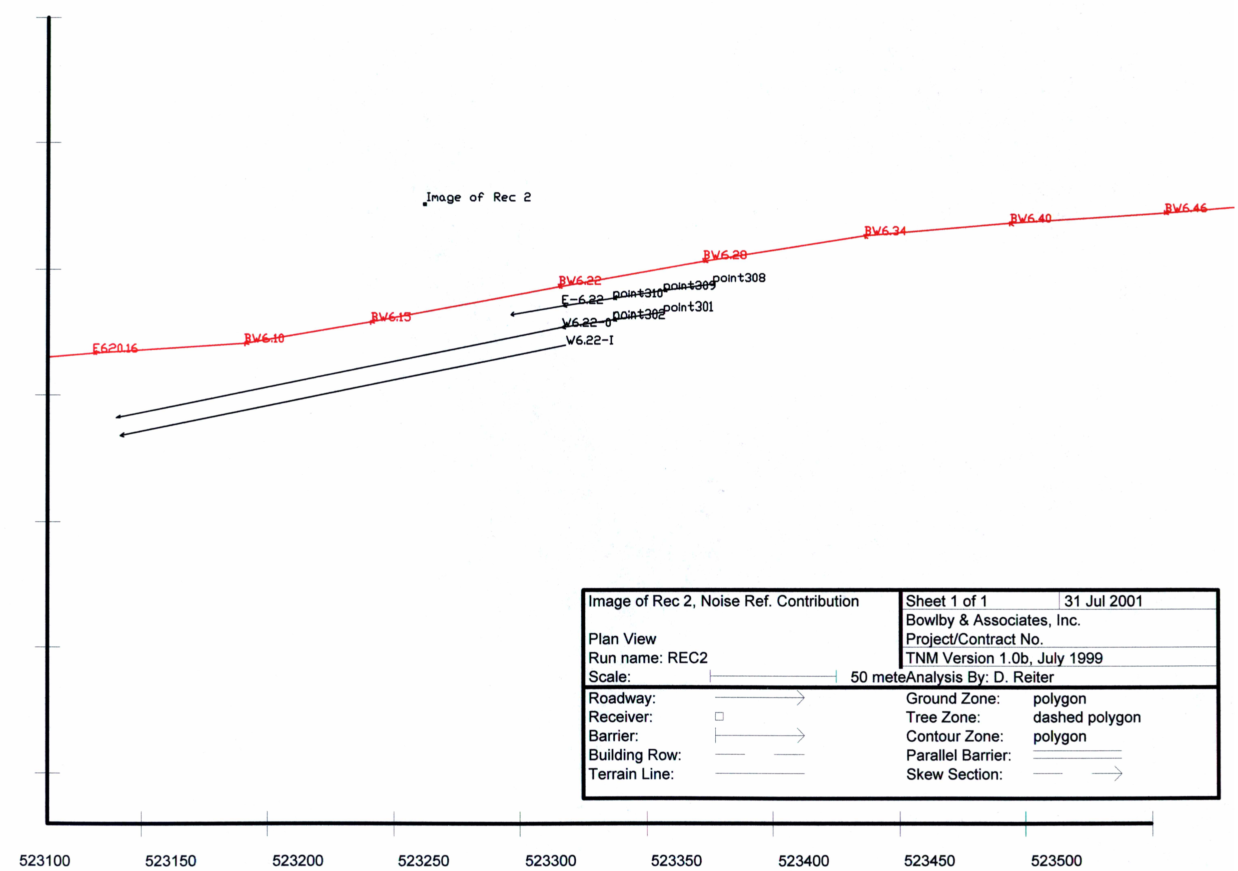

FIGURE 6 TNM plan view of roadway segments from which noise reflections will originate