Barrier Overlap Analysis Procedure

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Situations arise in which noise barriers are overlapped to accommodate highway entrance or exit ramps, service roads, local access roadways, underground utilities, or community desires regarding placement within the right-of-way. This arrangement of two parallel vertical barriers with an opening in between gives rise to the overlap noise barrier problem. The need to protect residential or institutional properties near the barrier opening led to the development of an analytical procedure to investigate the reflection-diffraction effects of overlapping barrier designs.

In many highway noise barrier designs, breaks are introduced in otherwise continuous noise barriers to accommodate entrance or exit ramps. Typically, a noise barrier along the highway is terminated at the ramp and then resumes on the service roadside, as shown in Figure 1. A break may be necessitated because of underground utilities or to provide access to shielded portions of the right-of-way. The presence of the break in an otherwise continuous noise barrier degrades barrier performance at receivers in the immediate neighborhood of the gap. To restore the integrity of the barrier, an overlap may be introduced to compensate for the presence of the gap. Problems that arise include how long the overlap should be and the amount of degradation due to the multiple reflection effect created between the overlapping barrier sections. The barrier overlap analysis procedure (BOAP) was developed to answer these questions.

A ray acoustics approach adopted to deal with the multiple reflection problem was combined with Maekawa's simple diffraction treatment for appropriate paths. Simplifying assumptions were made to provide an approximate solution of the problem. A FORTRAN version of BOAP was implemented on a PC for use as a supplemental noise barrier design tool in conjunction with STAMINA 2.0/OPTIMA (*1*) to achieve the most cost-effective barrier design.

ANALYSIS OF PROBLEM

To simplify the solution, the following assumptions have been made:

1. Barriers are vertical, parallel to each other and to the roadway,
2. Barriers are of equal height, and
3. Barrier edge diffraction arising during reflection is ignored.

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It should be noted that these assumptions may be dropped if more comprehensive procedures (*2*) are used, but at the cost of considerably greater effort. In addition, the double diffraction effect of barriers can be ignored and replaced by the most effective barrier assumption (*3*) as is done in STAMINA 2.0.

As in the simple barrier case, the sound level at a receiver due to a roadway segment is the sum of contributions from the direct rays (if any) passing through the gap and the diffracted rays passing over the most effective barrier. For overlapping barriers, however, an additional contribution resulting from multiple reflections in between the barriers must be accounted for. This is done by using the method of images and rectified rays. The contribution due to multiple reflection can be calculated by summing over the contributions of the roadway segments to each of the image receivers in the rectified geometry. The summation process is carried out until a prescribed convergence criterion is met. The reachable paths from a roadway segment to an nth-order image receiver after n reflections in between the overlapping barriers or diffracted over the nth image barrier after $n - 1$ reflections may be classified into four ray path categories or cases.

Figure 2a shows the first category (Case A) of diffracted ray paths with $n - 1$ multiple reflections; the corresponding roadway configuration, with left and right semi-infinite overlap barriers, is shown schematically. The first image of the left barrier and the second ($n = 2$) image of the right barrier and the receiver are also shown. The angle to the normal from the nth image receiver to the lip of the nth right barrier is denoted by N. Similarly, the angle to the lip of the first image of the left barrier is denoted by U, and the angle to the lip of the left barrier is denoted by L. In this case, $L > N$, and those rays originating from the roadway segment opposite the angle D ($D = U - L$) would reach the nth image receiver after $n - 1$ multiple reflections and a diffraction over the nth image barrier.

In the bottom half of Figure 2a, both the physical and rectified (virtual image) paths are presented for a typical ray, for $n = 2$. Every crossing of an image barrier by the image ray corresponds to a reflection of the real ray by a real barrier, except for the final crossing, which may be a diffraction by the (upper) barrier edge.

Case B, the second category, is characterized by paths that not only involve multiple reflection followed by diffraction as in Case A, but also by paths that involve no diffraction, as shown in Figure 2b. In this mixed case, when $U > N$ and $N > L$, those rays originating from the roadway segment opposite the angle D ($D = U - L$) would reach the nth image receiver after $n - 1$ multiple reflections and a diffraction over the nth image barrier, and those rays originating from the roadway segment opposite the angle R ($R = N - L$) would reach

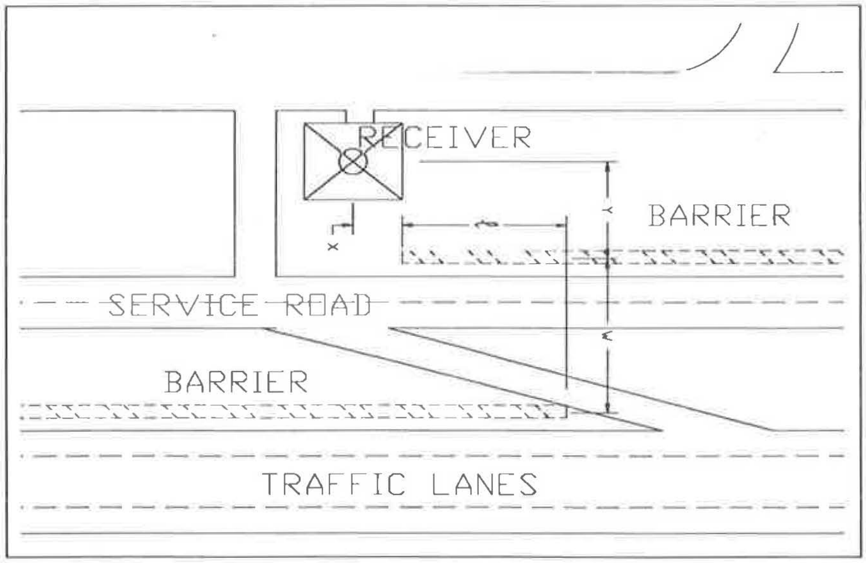

FIGURE 1 Overlap barrier at service road.

the nth image receiver after n multiple reflections in the rectified geometry, as shown in Figure 2b.

As the overlap shortens (Figure 2c), angle U is less than angle N, but greater than the vertex angle M to the lip of the $(n - 1)$th image of the right barrier (and $L > M$), pure multiple reflections occur (Case C2). Those paths originating from the roadway segment opposite the angle R ($R = U - L$) would reach the nth image receiver after n complete reflections. As the overlap shortens further, when $U > M$ and $L < M$, a partial multiple reflection category (Case C1) results (Figure 2d). Only that part of the roadway segment opposite the angle R ($R = U - M$) would have paths reaching the nth image receiver through n multiple reflections. No other reachable paths exist for multiple reflected rays.

It is easily seen that an overlap configuration consisting of a right bottom barrier and a left top barrier is but a reverse image of the problem shown. The preceding analysis and classification of the ray path construction led to the development of the following computational procedure.

PROCEDURE

Given a specific roadway-barrier-receiver geometry, the sound pressure level (SPL) at the receiver is computed by summing over the range of SPL values computed for the receiver and each of its images. For each receiver or its image receiver, the roadway contributions may consist of

1. The direct line-of-sight rays through the gap,
2. The simple diffracted rays over the left and the right barriers,
3. The multiple reflected rays from the overlapping barriers, and
4. The diffracted multiple reflected rays from the overlapping barriers.

Computation of the first two contributions is straightforward and can be modeled readily using STAMINA; computation of the last two contributions from the overlapping barrier sections may be greatly facilitated by applying the following formulation to the rectified geometry.

Let

x = horizontal distance from the receiver to the lip of the top right barrier,
y = perpendicular distance from receiver to the top right barrier,
w = width of the gap separating the barriers, and
l = length of the overlap section of the barrier (see Figure 1).

Then the ray classification angles N, M, U, and L may be readily computed for each image ($n \geqslant 1$) as follows:

$$\tan N = x/y$$

$$\tan M = x/(y + w)$$

$$\tan U = (x + l)/[y + (2n - 1)w]$$

$$\tan L = (x + l)/[y + (2n + 1)w].$$

The ray paths may be classified as

Case A:	$L > N$	$D = U - L$
Case B:	$U > N, N > L$	$D = U - N, R = N - L$
Case C2:	$L > M, U > M$	$R = U - L$
Case C1:	$U > M, M > L$	$R = U - M$

The computations for diffracted and reflected paths are based on the modified algorithms developed in the *FHWA Highway Traffic Noise Prediction Model* (*4*) as follows:

$$L_D = L'_{0i} + 10 \log \frac{N_i D_0}{S_i} + 10\,(1 + \alpha) \log \frac{D_i}{D_0} + 10 \log \frac{D}{\pi} + \Delta_{\text{barrier}} - 25$$

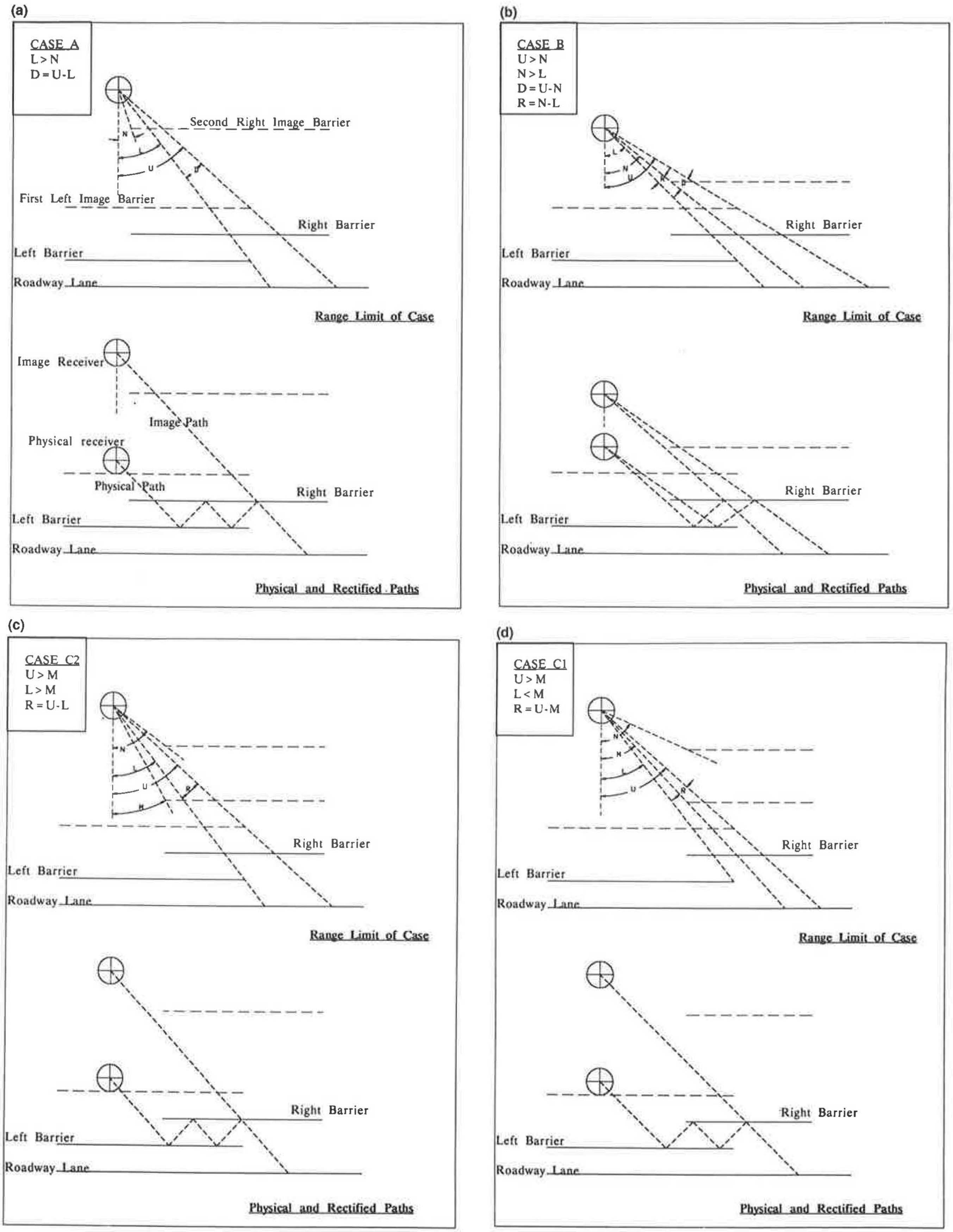

FIGURE 2 Ray geometries: a, diffracted multiple reflected rays; b, mixed multiple reflected rays; c, multiple reflected rays; d, partial multiple reflected rays.

$$L_R = L'_{0i} + 10 \log \frac{N_i D_0}{S_i} + 10 (1 + \alpha) \log \frac{D_i}{D_0} + 10 \log \frac{R}{\pi} - 25$$

respectively, for diffracted multiple reflected ray paths and multiple reflected ray paths without diffraction as categorized above, in which Subscript i denotes the ith vehicle type, L'_0 is the reference emission level at $D_0 = 50$ ft, the second term on the right hand sides is the traffic adjustment term for a vehicle type, the third term on the right hand sides is the distance adjustment term, the fourth term on the right hand sides is the modified finite roadway adjustment term, and Δ_{barrier} is a barrier attenuation term in the diffracted case.

The computations are carried out in the rectified geometry (i.e., all geometric parameters such as receiver-barrier distances are in reference to the nth image receiver and nth image left and right barriers). Provision for consideration of absorptive barriers is incorporated by replacing the reference emission level by a reflection-dependent term, and the atmospheric absorption effect is incorporated by adding an additional attenuation term to the distance-adjustment term.

COMPUTER IMPLEMENTATION

BOAP was implemented in two versions as an MS-FORTRAN program compiled and executed on an IBM-PC (and compatibles) with a math coprocessor. In the first version, SPL values are calculated for a grid of receivers, as shown in Figure 3, and noise level contours are plotted. In the second version, SPL values are calculated as a function of barrier overlap length for a single site-specific receiver. BOAP is programmed to start without any overlap, to increment the overlap by integral multiples of the width w between barriers, and to stop when no reachable multiple reflected paths exist. The convergence criterion for computation at each receiver is set as an increase in SPL of less than 0.1 dB over the previous calculation. As presently programmed, the grid version of BOAP may handle up to an 11-by-11 array of receivers.

The program also incorporates a small FORTRAN subroutine for computing octave-band atmospheric absorption coefficients under a given set of atmospheric conditions (pressure, temperature, and relative humidity). This subroutine implements American National Standards Institute S1.26 (5) for the calculation of the absorption of sound by the atmosphere.

SAMPLE APPLICATIONS

The development of BOAP is an outgrowth of New York State Department of Transportation (NYSDOT) project PIN 0227.86, Long Island Expressway Service Roads, Half Hollow Road to Commack Road, Suffolk County. This project involves completion of missing service roads and construction of mainline and service road noise barriers along a 5-mi section of I-495 through a residential neighborhood in Dix Hills, N.Y. Breaks in the noise barriers were necessitated by underground utilities, ramp-service road configurations, and community input regarding placement within the right-of-way.

An illustration of geometric input data required for the grid version of BOAP is shown in Figure 3. The nearest roadway is approximately 60 ft away from the left barrier. There is a gap of 15 ft between barriers, and an 11-by-11 grid (with only 5 rows and 8 columns shown) of receivers at intervals of 1

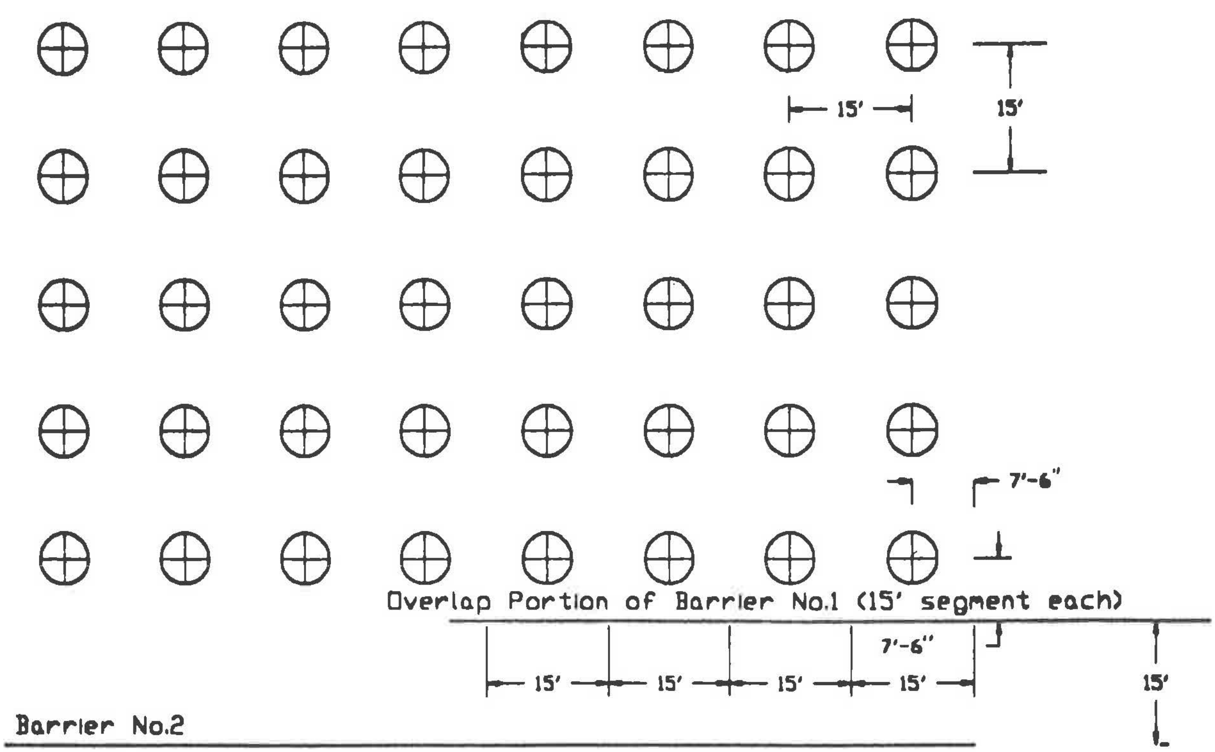

FIGURE 3 Geometry of grid sample application.

width apart starts at a half-width down and away from the tip of the right barrier without overlap (zero-width overlap). The traffic volume on the roadway is 5,650 veh/hr with a mix of 83 percent automobiles, 9 percent heavy trucks, and 8 percent medium trucks, and the average speed is 54 mph.

Figures 4 to 6 show the resulting noise level (in dBA) contour output plots obtained using the grid version of BOAP (with the 8-by-8 array shown in Figure 4 and with the 9-by-9 array shown in Figures 5 and 6) as the right barrier is extended from zero-width overlap to one-width overlap and to four-width overlap. Both X-axis and Y-axis in Figures 4 to 9 are measured in units of gap width between the barriers. In Figure 4, the gap between the barriers results in increases in noise levels in the immediate area adjacent to the opening in the form of a ripple, as would be expected. The ridge of the ripple is along the line-of-sight transmission path (as shown in the three-dimensional views in Figure 7) and decreases further from the opening. As the barrier overlap increases, the effects of the opening become more localized and diminish in magnitude as shown in Figures 5 to 7; the ripple effect due to the line-of-sight transmission through the gap is replaced by the ripple effect resulting from multiple reflection as shown in Figures 8 and 9. Figure 10 is a sample computer output at a single grid point (receiver at third row and second column of Figure 3); the output L_{eq} for the no-barrier and simple-barrier cases agree well with STAMINA 2.0 results to the nearest decibel.

Figure 11 shows the resulting output from a sample application of the single site-specific receiver version of BOAP. The receiver is located at X = 120 ft and Y = 30 ft from the edge of the right barrier, 230 ft from the roadway. The gap width between the barriers is 50 ft. The barriers are 25 ft in height, and the receiver elevation is 15 ft above ground with the same traffic conditions as the previous example. Figure 11 shows the localized multiple reflection effect (the difference between the upper curve and the lower curve in dBA) as the overlap is extended at 50-ft increments (one barrier gap width) towards the receiver. Without the barriers, the noise level at this particular receiver was estimated at 74 dBA. With the barriers (as configured without any overlap), the noise level would be reduced to 62.8 dBA. Extending the right barrier (the closer barrier) by 100 ft would reduce the noise level to 60.8 dBA if it were not for the multiple reflection effect (+2.4 dBA) between the overlapping barriers. The multiple reflection effect disappears as the right barrier is extended past the receiver, in which case no reflected ray would reach the receiver. For this particular receiver, then, barrier overlap would result in the degradation of barrier performance.

CONCLUSION

A procedure to analyze the effect of overlapping noise barriers has been developed and implemented on a NYSDOT project. It is shown that the gap between noise barriers results in increased noise levels in a localized region along a line-of-sight transmission path through the gap. Overlapped barrier sections used to compensate for the gap would introduce localized increases resulting from multiple reflections. The effect, however, is very dependent on the receiver-barrier-roadway geometry and must be analyzed on a case-by-case basis as illustrated by the sample applications discussed. In a site-specific situation in which the distribution of receivers near the gap is fixed, the procedures presented permit an optimal design of a barrier overlap configuration to provide the pro-

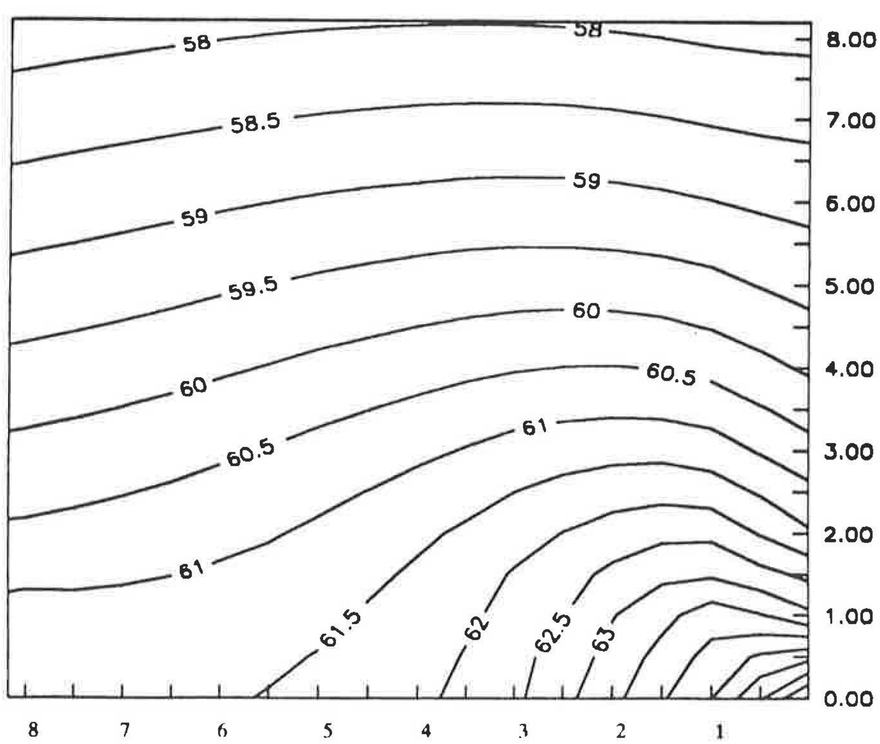

FIGURE 4 Noise level contours—zero-width overlap.

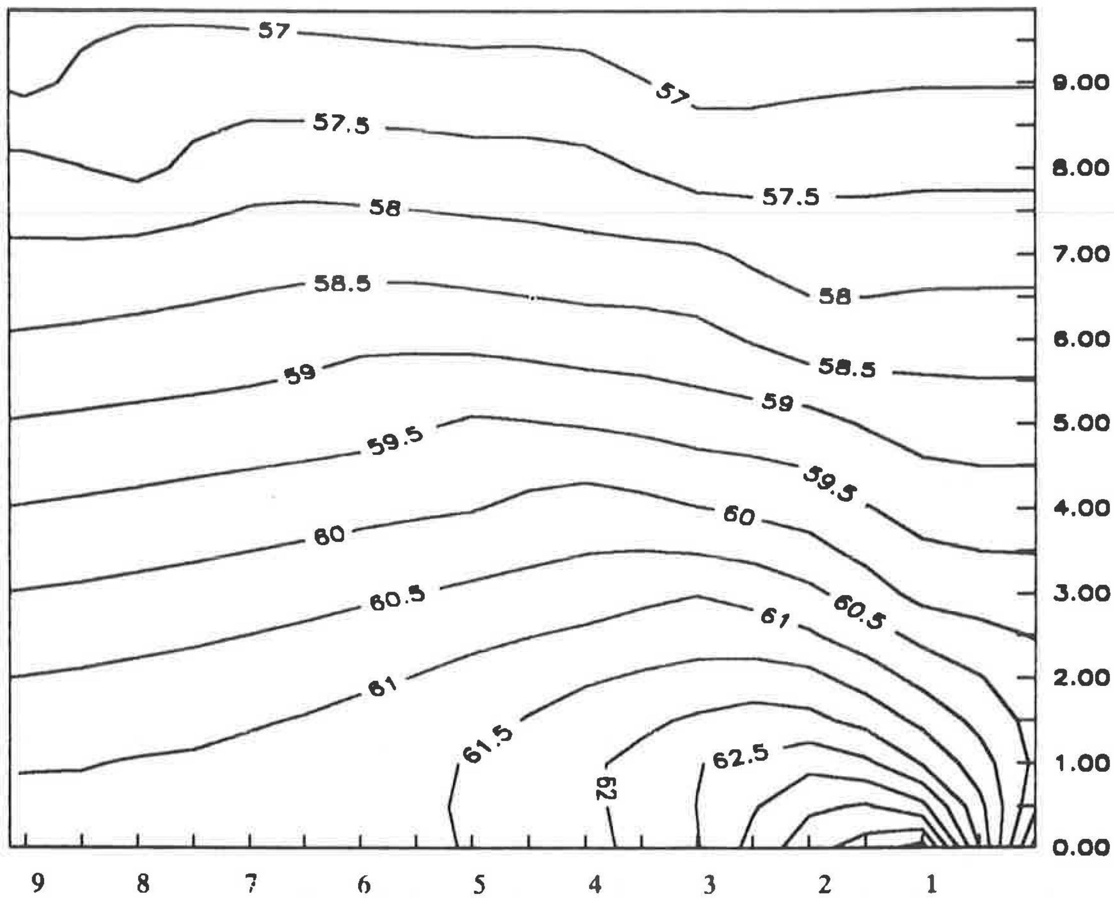

FIGURE 5 Noise level contours—one-width overlap.

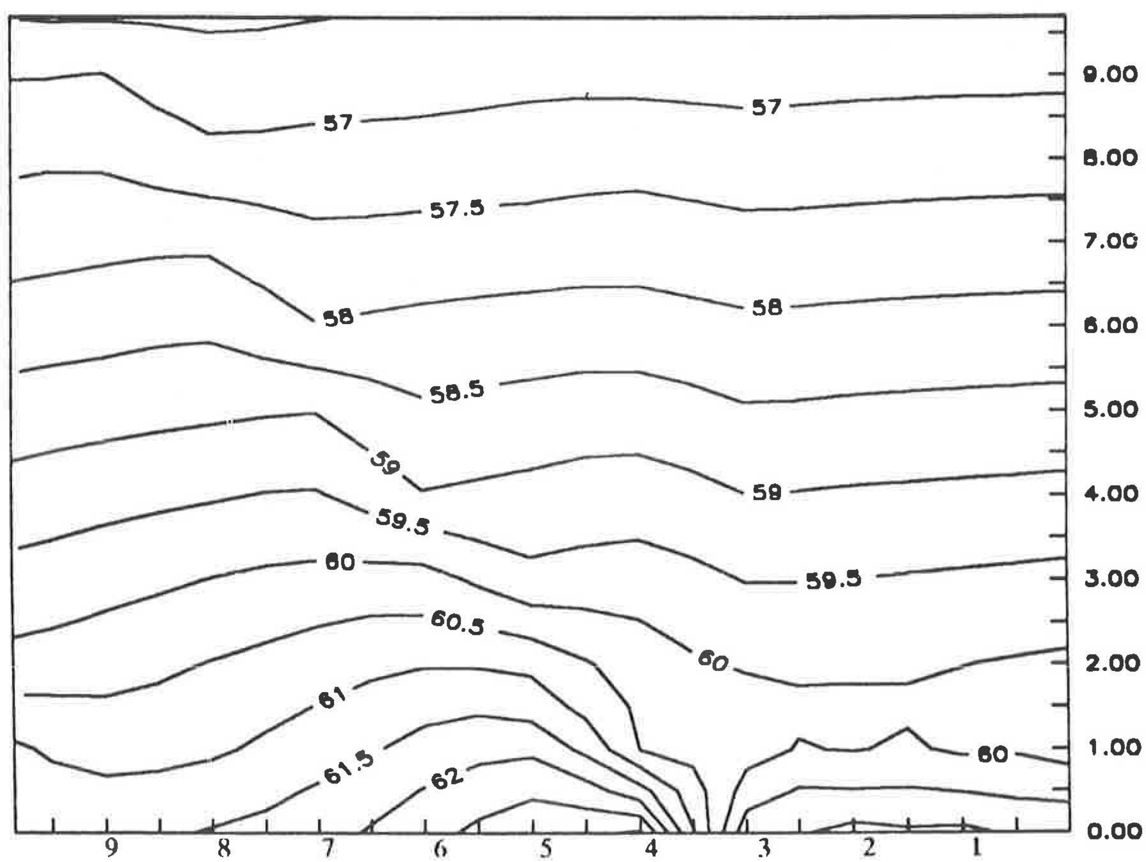

FIGURE 6 Noise level contours—four-width overlap.

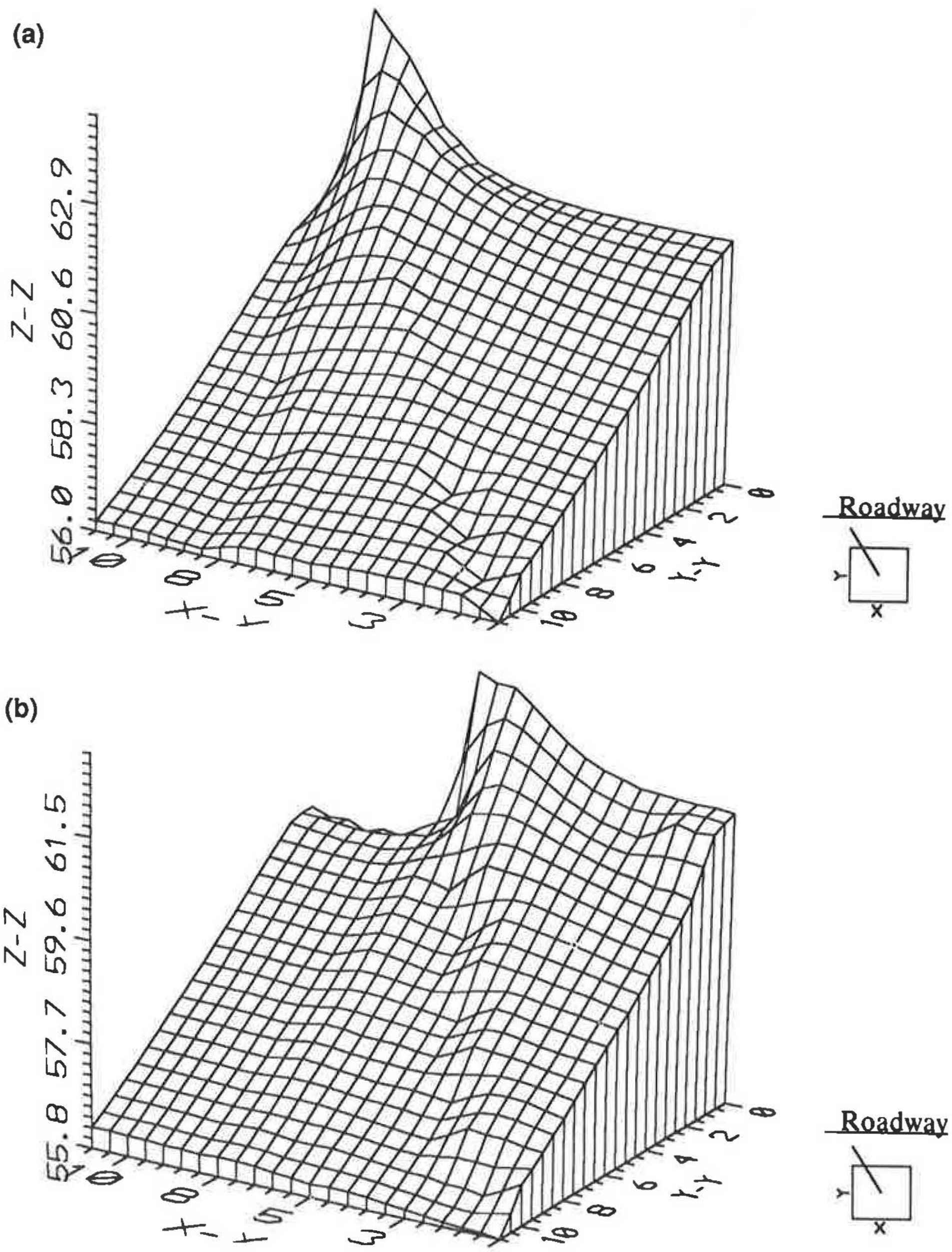

FIGURE 7 Three-dimensional noise level display: a, one-width overlap; b, four-width overlap.

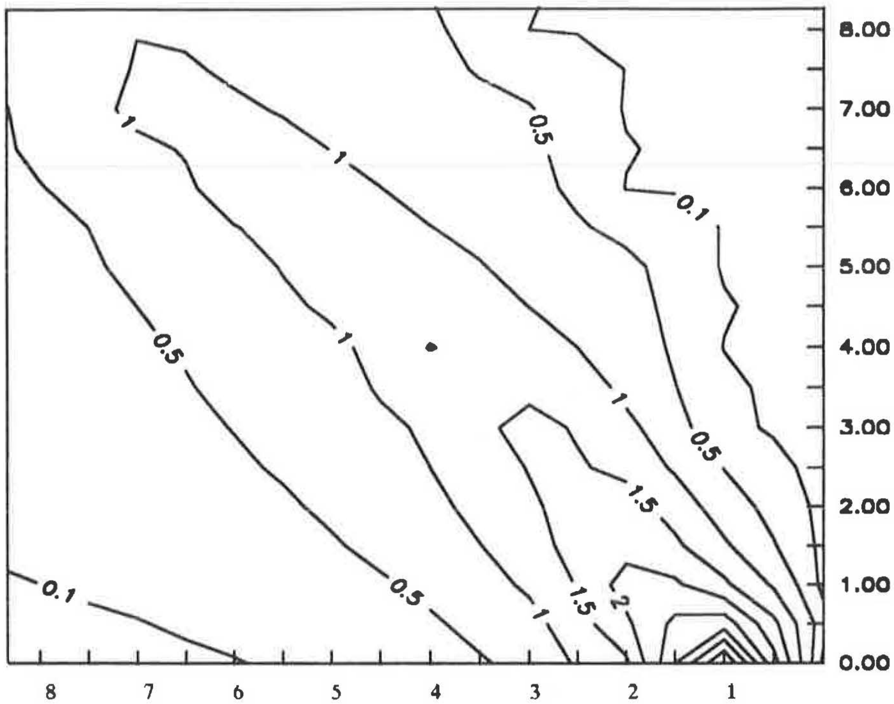

FIGURE 8 Multiple reflection effect—one-width overlap.

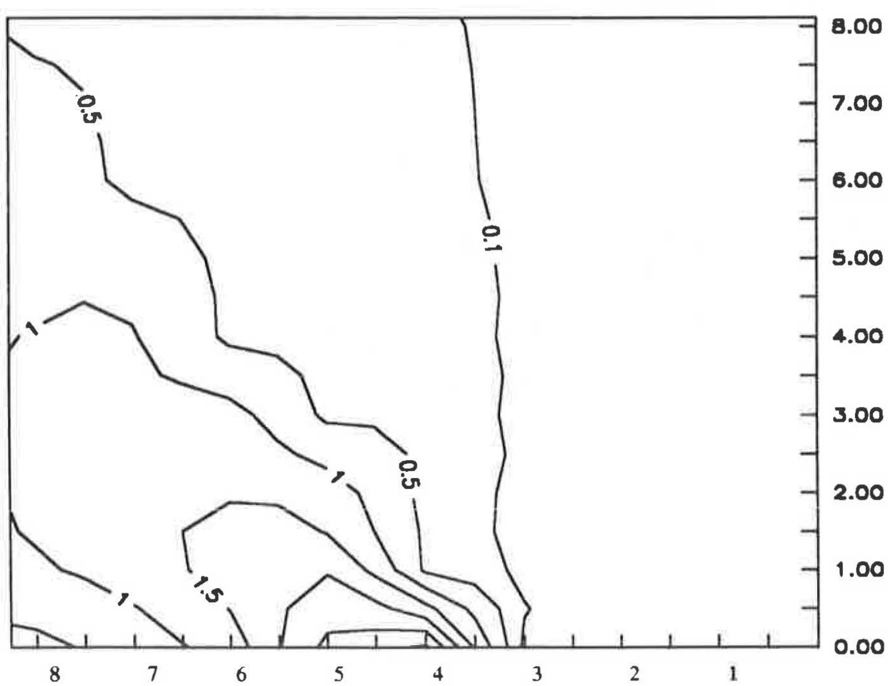

FIGURE 9 Multiple reflection effect—four-width overlap.

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Receiver at 3rd Row 2nd Column from 15' Gap

X1= 22.5   Y1= 37.5
X2= 22.5   Y2= 52.5
Distance to Rdwy.  105.0

Barrier   Elevation  =15.0
Receiver  Elevation  =5.0
Roadway   Elevation  =0.0

NO BARRIER LEQ=        77.996170
******************** Receiver may see gap   , Leq =     63.525240
ORIGINAL   Leq=67.523680
     CASE A:    ALEQD=47.839630
          1TH  IMAGE  TERM  LEQ=47.839700
     NEW  Leq  =67.570140

For overlaping length =    15.0 ft

ORIGINAL   Leq=65.296620
     CASE A:    ALEQD=50.823090
          1TH  IMAGE  TERM  LEQ=50.823120
     CASE B:    ALEQR=52.016870        ALEQD=45.661850
          2TH  IMAGE  TERM  LEQ=52.921120
     CASE C2:   ALEQR=54.627750
          3TH  IMAGE  TERM  LEQ=54.627770
     CASE C1:   ALEQR=40.527630
          4TH  IMAGE  TERM  LEQ=40.528020
     NEW  Leq  =66.025110
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FIGURE 10 Sample output from BOAP at a single receiver.

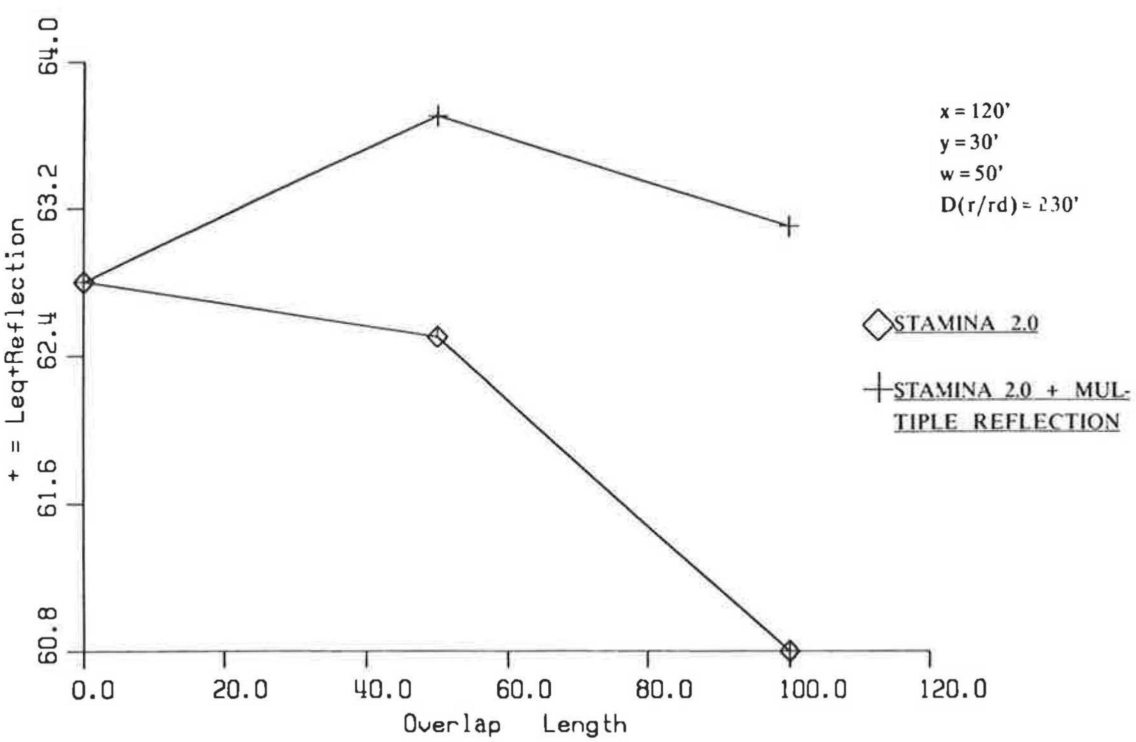

FIGURE 11 Effect of multiple reflection versus barrier overlap.

tection needed against the break in the barriers while avoiding the effect of multiple reflections on specific receivers.

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