SIMULATION VISUALIZATION OF HIGHWAY NOISE NEAR BARRIERS

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REPORT

Submitted to:

Mr. Mariano Berrios, Project Manager

The Florida Department of Transportation
Research Center
605 Suwannee Street, MS 30
Tallahassee, Florida 32399

Submitted by:

Roger L. Wayson, Ph.D., P.E.
Professor and Principal Investigator

In association with:

John M. MacDonald, Ph.D., P.E.
Angoli Martin, M.S.

University of Central Florida
Civil & Environmental Engineering
Community Noise Lab
P.O. Box 162450
Orlando, Florida 32816-2450
Tel: 407 823-2480
Fax: 407 823-3315

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16. Abstract

The objective of this research was to produce a simulation program that allows visualization of the shadow zone (area of reduced noise levels receiving at least 5 dB(A) of noise reduction) behind a noise barrier. This is extremely important for two reasons: 1. Noise barriers are built if the cost per benefited dwelling unit is below the threshold defined by FDOT. However, which dwelling units are benefited is often difficult to determine. This research will allow a visual indication of those dwelling units receiving benefits. 2. When dealing with the public, a picture is worth a thousand numbers. This research will allow a visual indication of the areas that receive benefits if a barrier were built to use when dealing with the public.

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OBJECTIVE

The objective of this research was to produce a simulation program that allows visualization of the shadow zone (area of reduced noise levels receiving at least 5 dB(A) of noise reduction) behind a noise barrier. This is extremely important for two reasons:

1. Noise barriers are built if the cost per benefited dwelling unit is below the threshold defined by FDOT. However, which dwelling units are benefited is often difficult to determine. This research will allow a visual indication of those dwelling units receiving benefits.
2. When dealing with the public, a picture is worth a thousand numbers. This research will allow a visual indication of the areas that receive benefits if a barrier were built to use when dealing with the public.

INTRODUCTION

The FHWA and State Departments of Transportation use the Traffic Noise Model (TNM) to predict sound levels generated at wayside receivers from automobile sources. These models also predict various propagation effects and are used to design noise abatement barriers. One of the deficiencies of TNM is that the theoretical shadow zone extents may be predicted further than occurs in reality since effects such as background noise is not considered. In the real environment, the shadow zone terminates where background sound levels from a variety of sources encroach upon the diffraction effect of the barrier. A project was undertaken by the University of Central Florida, sponsored by the Florida Department of Transportation, to evaluate the effectiveness of nineteen barriers in the state of Florida [1]. Data collected during this project was used to establish the shadow zone length for each barrier and an empirical model was developed from these results to predict the length of shadow behind a generic barrier with the general topography [2]. The length of the shadow zone, where 5 dB(A) of insertion loss (IL) is still maintained, is based on the TNM predicted insertion loss of the barrier at 30 meters behind the barrier.[1] This accounts for many of the propagation variables which TNM predicts quite well. This paper details the methodology and the development of a computer model (FDOT shadow) to assist during calculations using TNM in estimating the boundary of the shadow zone behind the barrier. A dxf[2] file and a coordinate ASCII[3] file are generated to allow use as an overlay in TNM or generate output using CAD programs. Either will allow a more visual recognition of the true shadow zone fringes and where benefited receivers truly exist. In cases where a receiver lies very near or just outside the boundary, additional modeling with TNM may be required.

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[1] In the paper, behind the barrier refers to the opposite side of the barrier from the highway.
[2] dxf, Digitial exchange format.
[3] ASCII, American Standard Code for Information Interchange.

METHODOLOGY

The method used to construct the shadow boundary behind a barrier begins with the following assumptions about the barrier/roadway scenario itself.

1. the shielded roadway lies parallel to the barrier
2. the barrier and receiver areas are located on semi-flat plane, ie close to the same elevation (typical of most Florida locations)
3. areas being evaluated are residential in nature
4. barrier coordinates entered into TNM are sequential
5. reasonable results are achieved using TNM during modeling

Work from the FDOT barrier evaluation project [2] performed by the University of Central Florida allowed an empirical method for the shadow zone to be developed based on measured results. Many different variables and methods were evaluated but one simple method provided essentially the same statistical results and was chosen for simplicity. The "heart" of this methodology is shown below as Equation (1).

$$SZL = 52.2 \exp(0.17 * IL_{TNM}) \quad [1]$$

where:

SZL = distance to edge of the shadow zone, feet
IL_{TNM} = insertion loss of barrier design from TNM at a location 30 meters (~ 98 feet) behind the barrier, dB(A)

Of importance is the shadow zone edge is defined as the distance from the barrier to where at least 5 dB(A) of insertion loss (IL) is achieved.

The independent variable is the TNM generated insertion loss value (IL_{TNM}) for each barrier section at a distance of 30 meters (98 feet) from the barrier. This distance was found to be well within the shadow zone for all but the very short barriers and provided a good calibration point for the methodology. Based on typical background levels found in the residential areas this permitted the limit of the shadow zone to be determined. Of note is that it is assumed the TNM results have been checked and are providing reasonable results. Best results occur if the TNM results compare well with measured values.

Since the TNM value is a calibration factor and assumed to accurately depict the sound levels deep in the shadow zone, the methodology requires a TNM receiver to be placed behind each barrier section. However, where the barrier is at a constant height, traffic is not changing, and there are no unusual changes in the terrain or buildings, only one value of the IL is required and can be repeated for each barrier section during the shadow zone model input. However, where barrier height changes occur, near the end of the barrier, if changes in topography of buildings exist, or if traffic mix is drastically changing, receivers at a distance of 30 meters behind the barrier should be modeled in TNM for each barrier segment and used as input to FDOT Shadow. Receivers in the immediate vicinity of other modeled diffraction objects, such as building rows, should be avoided for best results.

Once the length of the shadow zone has been approximated, the outer boundary away from end effects is determined. The end effects that occur near the ends of the barrier as sound encroaches into the shadow zone by diffracting around the barrier must also be considered. TNM currently uses an approach based on source paths around the ends of a barrier. This slightly over estimates the shape as shown by field measurements since diffraction is also occurring around the ends of the barrier just as it is over the top.

To better approximate the end effects, both mathematical modeling and field validation measurements were performed. The mathematical modeling required developing a method to estimate edge diffraction of the sound rays as they encounter the end of the barrier. The Kurze and Anderson methodology [3] was used as the starting point. Using this formulation, a grid of sources and receivers were analyzed based on a heavily traveled roadway, acting close to a true line source. A review of the resultant insertion losses at each receiver in the grid permitted an estimate of a shape function of the shadow zone at the barrier boundary end points. Multiple cases were evaluated to determine the optimal shape. Figure 1 is a graphical presentation of the end shape. Of note is that the actual dimensions vary according to the actual barrier dimensions, barrier shape, and local conditions but the overall shape is assumed to remain constant. As such, this shape function is not used as an absolute value but is scaled to define the shadow zone shape at the barrier end points based on the depth of the shadow zone which was previously determined (see Equation 1) and conditions at the end of the barrier.

This shape was then verified by field measurements. Figure 2 depicts sound pressure levels (colored bands) measured behind a barrier along Interstate 4, in Lakeland, Florida. The “edge effects” of the barrier are noted by observing that the point (0,0) is the end of the barrier and distance away from the barrier end are represented along the “x” axis. It can be seen that as predicted, the measured sound levels diffract around the edge of the barrier due to the line source nature of the roadway and diminish the shadow zone near the end of the barrier. To make the definition of the shape more visible to the reader, Figure 3 depicts this same in-situ barrier measurement but plotted with insertion loss rather than sound pressure level as the variable of interest. Of note is the general shape, which matches the mathematical conclusions. The colored bands of interest are the 5 dB(A) insertion loss region where there is a transition from dark blue to light blue (cyan).

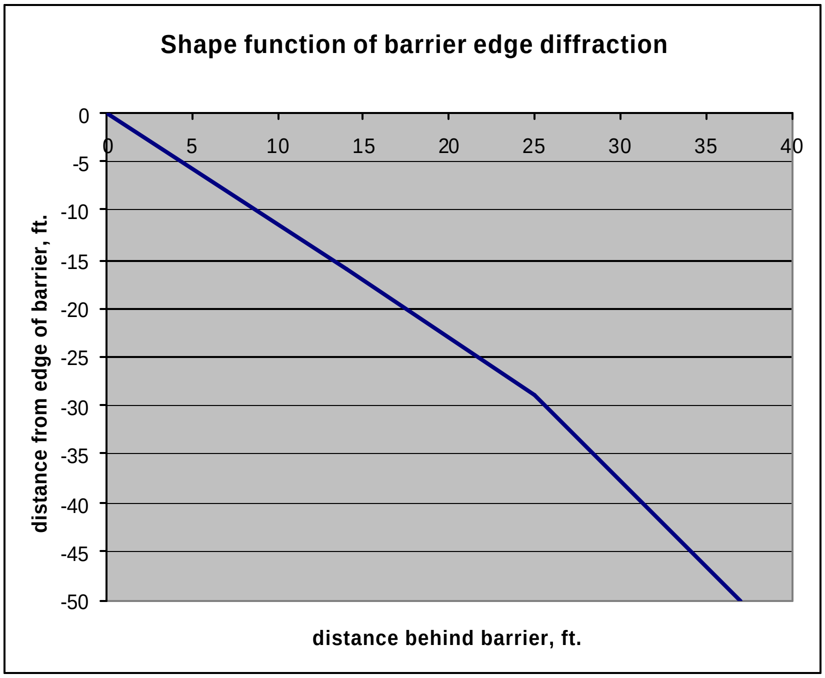

Figure 1. Barrier Edge Diffraction Shape Function.

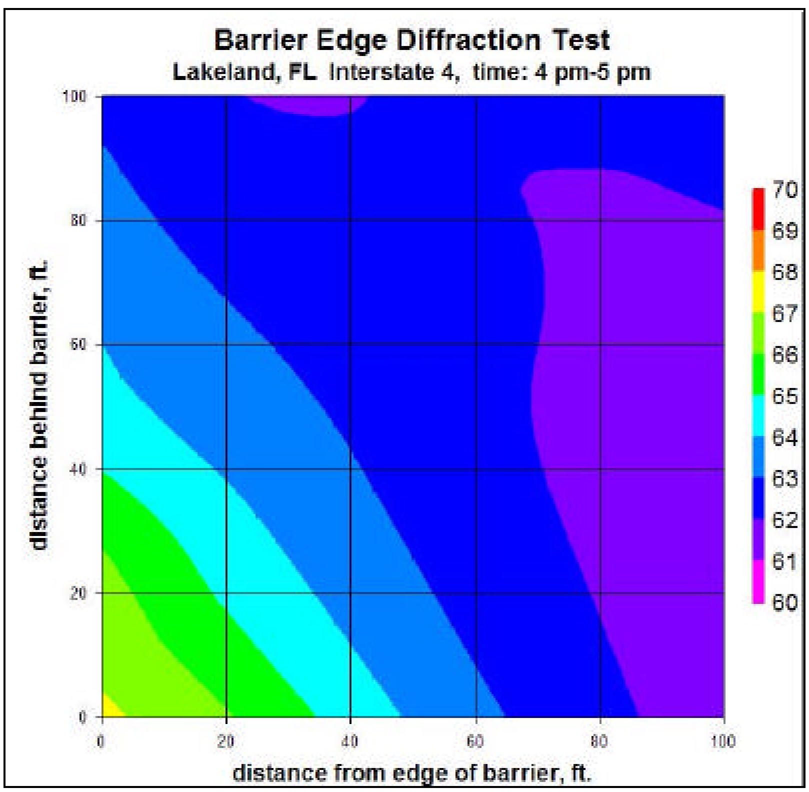

Figure 2. Sound Pressure Levels Measured Behind an Interstate Barrier.

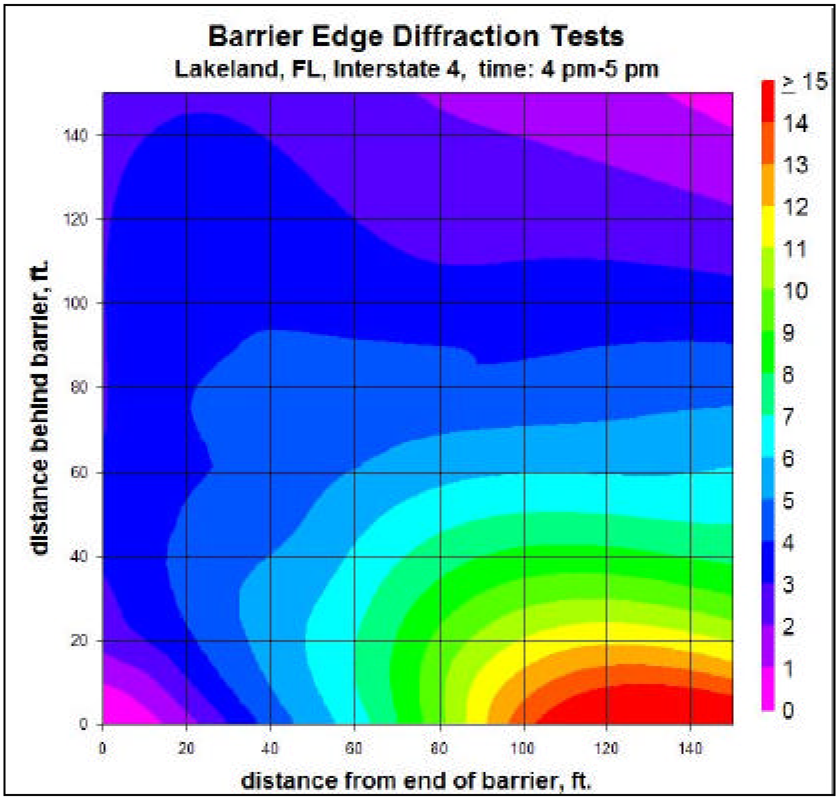

Figure 3. Insertion Losses Measured Behind An Interstate Barrier.

Figure 4 depicts the "shape function" that were developed by using the method based on the Kurze and Anderson diffraction methodology (K&A Simulation) as compared to the field measurements that were shown in Figures 2 and 3. Again, this shows the theoretical method is largely confirmed by the in-situ barrier measurements.

The results provide the boundary for the end of the barrier and combined with the other results provide defined shadow zone boundaries. The shadow zone is bounded by the barrier (per user specified coordinates), the length of the shadow zone (as determined by Equation 1), and the diffraction occurring at the ends of the barrier (based on the shape function of Figure 1). The shadow zone program automatically computes the coordinates of this defined boundary for the user based on the plane established by the barrier coordinates.

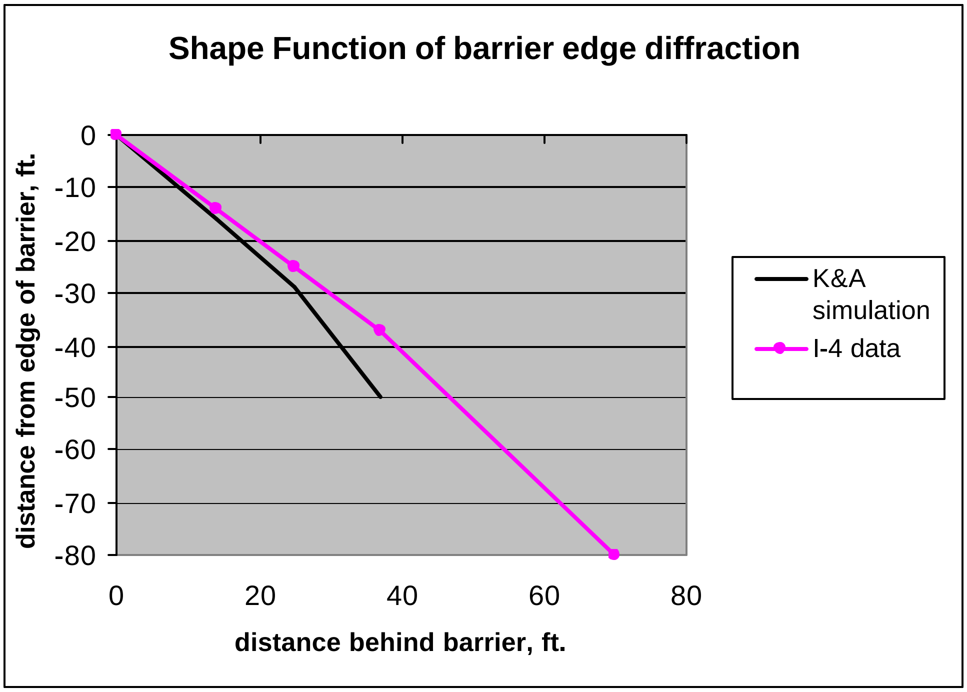

Figure 4. Barrier Edge Diffraction Shape Function.

The shadow zone program computes the coordinates of each shadow zone boundary point in relation to the barrier and displays a graphical plan view representation of the zone. To allow the proper location in the ground plane, the axis must be determined. This is done by using the barrier coordinate information, provided by the user. These values are those coordinates from the TNM run. Using axis transformation and some other geometric calculations for the case of a general barrier design the shape is determined. As previously noted, straight barriers are a simpler implementation. TNM_{IL} values from one receiver are representative of other locations in the same region behind the barrier. This results in a need to model only a single receiver in TNM along this stretch of barrier. However, if a barrier has sections of different heights, if traffic mix is changing, near the end of the barrier, or if the local topography (including buildings) is changing, this must be taken into account by increasing the number of reference points. This is done by modeling more location in TNM to determine TNM_{IL} for each barrier section.

The methodology of implementing the shape function and determining shadow zone coordinates behind the barrier is complicated when barrier “wings” or wrap around sections are encountered. This causes problems since the program will interpret this as two separate barriers because of the strong intersection angle of the two barrier sections. The methodology, without changes, would attempt to place a shadow zone boundary point inside the actual shadow. This results in intersecting zone coordinates and problems. It was considered just requiring the user to indicate a barrier wrap section but this added unneeded complexity for the user during input. For this reason it was decided to design an algorithm that detects a barrier wrap section. The algorithm is based on the angle that the barrier section makes with the next barrier segment. The detection algorithm worked well with the test cases from the Barrier Insertion Loss project [1] and for that reason it was used in this methodology leading to simplified user input.

The computer implementation of the shadow zone methodology (FDOT Shadow) will permit a dxf file to be written. This is done by user selection and the shadow zone coordinates are placed as line objects into a user named dxf file. The dxf file can be imported directly into the TNM model to determine benefited receivers by counting those receivers that lie within the boundary created by the barrier and the shadow zone outline. It may also be used with various CAD programs to create other objects, layers in the file, or overlaid on files such as aerials to allow benefited receivers to be more easily determined. The output can also be used for documentation purposes.

RESULTS

A methodology to predict the shadow zone resulting from installation of a noise barrier along highways has been defined. The computer implementation of the methodology (FDOT Shadow) has resulted in a simple to use program with a minimum of inputs. However, it does require the user to have first run TNM for specific receiver locations. This is not seen as a tremendous amount of extra work since TNM is required by FHWA and FDOT for projects requiring a detailed noise analysis. Consideration of a barrier would surely require a detailed noise analysis. As such, addition of receiver locations is the only additional effort required to provide the needed input for FDOT Shadow.

The end result is a visual indication of the shadow zone allowing a quicker and easier method to determine the total number of benefited receivers. Additionally, the graphic dxf output and coordinate file can be used both in TNM and CAD for other purposes such as displays when dealing with the public, graphical overlays to determine benefited receivers more easily, or for importing into TNM to help with benefited receiver determination.

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