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Selected Acoustical Parameters of Highway Noise Barriers

An NCHRP staff Digest of the essential findings from the final report on NCHRP Project 3-26, "Investigation of Selected Noise Barrier Acoustical Parameters," by S. I. Hayek, J. M. Lawther, R. P. Kendig, and K. T. Simowitz, The Pennsylvania State University, University Park, Pa.

THE PROBLEM AND ITS SOLUTION

Introduction and Objectives

Noise barriers are being constructed more frequently both along new highways and along existing highways where traffic noise intrusions have stimulated concern. Because barriers are typically a responsibility of state highway agencies, highway planning and design engineers are being called on to assess the needs for noise barriers and to predict their effectiveness. Yet in the past design manuals for these purposes have often presented difficulties. Even improved techniques have led to situations where the predicted effectiveness of a barrier has differed from results observed after its construction. Part of the reason is that current highway noise design guides are based on models that do not account for such effects as changes in barrier tilt, application of surface impedance, or departures from a thin-wall cross section.

Therefore, a need existed (a) to determine the influence of selected barrier characteristics on barrier performance and (b) to develop procedures to incorporate these effects in the design process. Thus, the objective of this investigation was to examine the manner in which noise propagates over barriers of different cross-sectional shape (e.g., thin walls, sharp wedges, trapezoids, walls on trapezoids, and round-topped berm-like shapes). An additional objective was to investigate and describe the effect of the terrain cover behind a barrier and the effects of partially absorptive barrier coverings on the net effectiveness of noise abatement behind a barrier.

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Research Scope and Approach

The research aimed at accomplishing these objectives was theoretical in nature, being based on adaptations of previously developed theory and carried out with explicit assumptions about conditions of highway alinement, source characteristics, ground surface, and so on. The models thereby reasonably represent realistic highway noise situations.

The series of subtasks designed for the project included the following:

1. Input-Output. This task set up items common to all or most of the study, such as source geometries, source spectra, receiver locations, barrier configurations, and barrier impedances. It also developed plotting programs and a program for implementing an incoherent line source. Figure 1 shows the variety of barrier geometries tested. Altogether, more than 550 barrier and terrain cases were selected for computation. This includes more than 60 runs with the *Noise Barrier Design Handbook* prediction model for an infinite source line. A table look-up routine was developed for computations via this model.

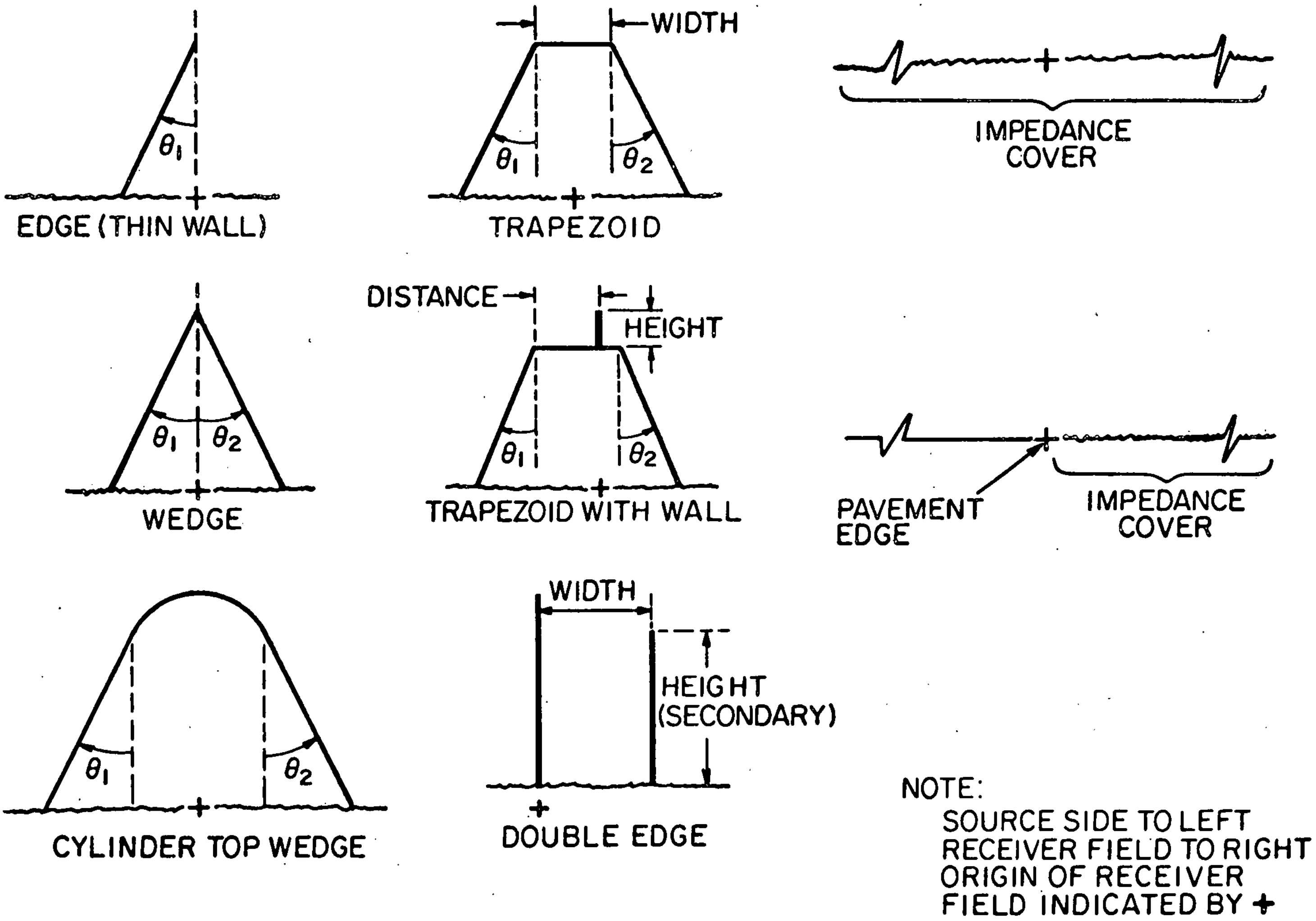

Figure 1. Cross sections of barrier types and ground sections modeled in the Project 3-2 investigation.

2. Ground Effects. This included reviews of ground effects models, selection and implementation of two models, and necessary computations. One of the two models deals with propagation over an impedance-covered plane. The other incorporates the pavement edge impedance discontinuity in the boundary. Appendix B of the agency's final draft report describes the detailed procedures for this work.

3. Barrier Model. For each of the selected barrier configurations (knife edge, double knife edge, sharp wedge, flat-top wedge, flat-top wedge with supported edge above, and round-top barrier), available theoretical models were modified as needed to represent the desired conditions. Point receiver noise values were computed and summed incoherently over a source line. By comparison with free-field noise computations, the excess attenuation was calculated and then plotted in contour format (see Fig. 2 for an example). Appendices C, D, E, and F of the project report describe the models; Appendix G lists all software developed for the project; Appendix H is a glossary of the acoustics terminology used in the report.

Nature of Results

The project has been highly successful in accomplishing its objectives. As yet, however, and pending follow-on work, the results have only limited applicability in practice. As noted, the effects of the barrier parameters were explored in theoretical terms. A second phase of the project, started in 1978, is expected to validate these findings by scale-model testing and measurement. Even so, the current research results will be of interest in their own right to at least two audiences. For readers who are not acousticians, the report has been designed to communicate some feeling for the impacts of the selected barrier parameters on barrier attenuation and insertion loss. For acoustic specialists, the report seeks to provide tools for modifying design manuals. This latter group will find that the report appendices offer comprehensive details for their consideration.

FINDINGS

Nature of the Findings

The project findings are basically of two different types. One pertains to attenuation effects of both barriers and terrain with respect to free-field conditions. These findings include comparisons between the models selected for this study and those for barrier attenuation reported in *NCHRP Report 174*, "Highway Noise—A Design Guide for Prediction and Control," and the Federal Highway Administration's *Noise Barrier Design Handbook*. They also include comparisons between barriers of differing geometries and impedance covers, and predictions of the excess attenuation of ground impedance over free-field noise propagation.

The second type of finding pertains to propagation over a barrier in the presence of the ground. These findings include results of computations on the relative sizes of various ground effect components in the presence of a barrier. Examples of barrier insertion loss computations are presented.

The project findings are listed in Chapter Two of the report under the headings:

Thin-Wall Barriers - Free-Field Comparisons
Sharp Wedges - Free-Field Comparisons
Round-Top Barrier - Free-Field Comparisons
Paired Edges - Free-Field Comparisons

Trapezoidal Barrier - Free-Field Comparisons
Trapezoid With a Thin Wall - Free-Field Comparisons
Ground Effects - Free-Field Comparisons
Noise Barrier in the Presence of the Ground

The findings are presented primarily in the form of figures similar to Figure 2, supplemented by text discussion.

Principal Conclusions

The conclusions of the investigation are assembled in two groups, one encompassing conclusions dealing primarily with barrier attenuation relative to free-field conditions, and the other dealing primarily with ground effects. Conclusions concerning insertion loss are included in the second group.

Barrier Attenuation

1. The investigation considered the effects on barrier attenuation of varying each of a number of geometric and surface impedance parameters. All the effects investigated, when accounted for by the more complete modeling of the present program, are found to be appreciable. The range of variability, including only geometric departures of a fairly simple nature, is at least 6 dB, over barrier cases that are considered equivalent by current procedures. Current procedures predict values near the low attenuation extreme of this range.

2. The investigation defined some barrier geometries which, on paper, offer attractive possibilities for increasing barrier effectiveness up to 10 dB or more in some instances. These geometries, which provide double shadowing of receivers from the highway, are double walls, trapezoids, and trapezoids topped by walls. Because the models from which the double shadowing effects are predicted are approximate, it is not clear that the predicted gains can be fully realized. Nonetheless, they are significant.

3. The attenuation of the hard, vertical, thin-wall barrier, as predicted by the more complete model of this investigation, is from 1 to 4 dB greater than that predicted by the *Noise Barrier Design Handbook* for a barrier of the same height. The greatest differences between the two predictions occur some 500 ft behind the barrier and beyond.

4. The effect of tilt on the attenuation of hard thin-wall barriers is negligible for angles of 45° or less from the vertical. Hard thin walls of greater tilt angles from the vertical are unlikely to be considered for structural reasons, but, in any case, make poorer barriers as their tilt angles from the vertical increase. A 15-ft-high, hard thin wall, tilted 70° from the vertical, has approximately 2 dB less attenuation than a vertical, hard thin wall of the same height.

5. Hard-surface, sharp-wedge barriers with interior angles of 90° or less, symmetrical about the vertical, may be treated as hard vertical thin walls of the same height. Symmetrical hard wedges with larger interior angles become increasingly poorer barriers, however. A symmetrical hard wedge of 140° interior angle, for example, has 2 to 5 dB less attenuation than a hard vertical wall of the same height. The difference between the two, within this 2- to 5-dB range, depends on receiver location.

6. Tilted hard-surface wedges (i.e., wedges asymmetrical with respect to

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(Case type)   CYLINDER      THE1= 20.0    HEIGHT= N.A.     Z1: H
(Vehicle)     CAR           THE2= 20.0    DISTANCE= N.A.   Z2: SB
(Offset)      120.0         WIDTH= 5.0                     Z3: H
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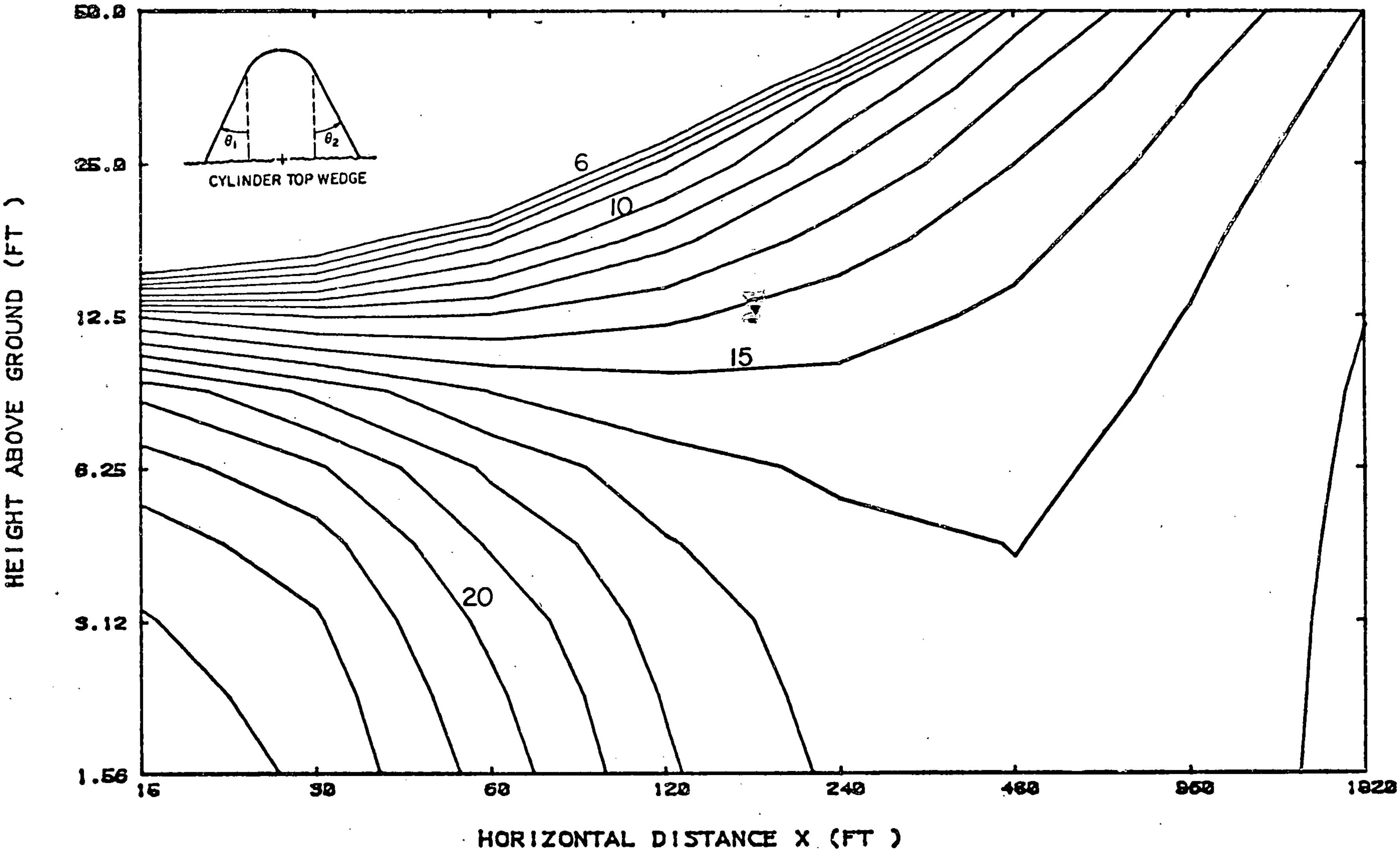

Figure 2. Typical barrier characteristic identification and attenuation contours in 1-dB increments. In this case, the noise source is passenger car traffic along a line offset 120 ft from the origin of the receiver field. The barrier is 15 ft high, has a cylindrical top 5 ft wide (for the circumscribed trapezoid) with Soundblox impedance levels, and hard sides sloped at 20° from the vertical.

the vertical) are poorer in performance than are symmetrical wedges of the same height or the hard thin wall formed by removing either side of the wedge.

7. When thin walls or wedges have absorbing surfaces, their barrier attenuations are improved. Considering only the vertical wall, the improvement is only about 1 to 2 dB, diminishing with distance. On the other hand, for walls or wedges with an absorbing surface sloping gently upward from near the highway edge (tilted 70° from the vertical, say), the effect of the absorption is more pronounced, especially for sources near ground level. The deleterious effects of tilt are then more than offset, and the attenuation may be as much as 2 to 6 dB greater than that of the hard vertical thin wall.

8. The presence of materials with absorptive or partially absorptive surface impedance on the top of a trapezoid barrier or a cylindrically-topped-wedge barrier enhances barrier excess attenuation. For impedance strips 5 to 10 ft (1.5 to 3.0 m) wide, the useful enhancement may be as much as 3 to 4 dB.

9. The effect of coatings on the highway side of a wall is enhanced by coating the other side as well.

10. Increasing barrier thickness in itself is not necessarily useful beyond that required to attain adequate transmission loss. A hard wedge is not as good as a hard thin wall if both are impenetrable to sound.

11. Double shadowing by parallel walls seems to be more effective than shadowing with a trapezoid or with a cylinder-topped barrier, even when the last two are impedance covered.

Terrain Attenuation

12. The traffic noise propagation process has been demonstrated to be sensitive to a number of terrain variables. An extension of currently approved modeling procedures to include their effects should result in improved prediction accuracy. The models developed in Project 3-26 are based on assumptions that are not universally accepted, however, and should be tested by experiment.

13. At least when the ground can be regarded as a plane, impedance-covered boundary and when atmospheric turbulence is low, the coherence of the ground reflections with the direct-path noise emanating from each element of the traffic stream cannot be neglected.

14. The effect of the highway pavement strip and its hard border on propagation of traffic noise over an adjacent impedance surface, such as grassy terrain, is significant. When dominant traffic sources are close to ground level and when the shortest path from a source line stretches over 60 ft or more of hard boundary before reaching the edge of the absorptive terrain, the pavement effect may amount to as much as 7 dB. For source lines closer to the pavement edge, or higher above the pavement, the effect diminishes.

15. The observed dependencies of the pavement effect on source height and source distance from the pavement edge introduce complications when the effects of multiple traffic lanes or of mixed source heights are combined. Present design manuals appropriately recommend lane-by-lane and source-by-source-height accumulation of component intensities at receiver positions, but a less accurate "equivalent-lane" technique is sometimes proposed for quick-look estimates of multi-lane situations. The "equivalent-lane" concept, as presently formulated, is based on too simplified a model to expect consistent predictions to result.

16. The so-called "ground wave" contribution to the sound intensities above grassy terrain cannot be neglected when the source height above the pavement is small, even when the source line is as much as 120 ft from the pavement edge. The contribution of the ground wave diminishes rapidly, however, as the source height is increased. For a source line standing 15 ft above uniform grassy terrain, the augmentation is less than 1 dB at all receivers higher than about 4 ft (1.2 m) and closer in range than 500 ft (153 m). Similarly, because sound propagation over a barrier raises the effective source height of the sound reaching the shadowed region, the ground wave contribution may be expected to be small there. If so, the difficult problem of computing the sound intensity resulting from diffraction over a barrier/impedance-cover combination is greatly simplified, because the effect of the ground may then be adequately accounted for by considering simple image sources.

17. The noise attenuation effect of absorbent terrain adjacent to a highway is partly, but not completely, removed by the erection of a noise barrier. Insertion loss findings differ quantitatively and range at least ±4 dB from values predicted using currently accepted procedures. In fact, the insertion loss of a barrier over grassy terrain is a complicated function of receiver position. Contours of constant insertion loss differ substantially in shape from barrier attenuation contour predictions relative to free field.

18. There is a need to expand the treatment of the effect of the ground in highway noise design guides and barrier prediction procedures as soon as questions of deterioration of coherency with turbulence and terrain irregularities can be clarified. The present findings and others available through exercise of the present models will be helpful in the consideration. The models themselves are too detailed for routine applications.

Suggested Research

In view of the importance of some of the conclusions, the report recommends that an experimental validation effort be mounted. Areas of particular interest are identified as:

1. Pavement surface effects.
2. Near-grazing-incidence effects over impedance boundaries.
3. Double-diffraction effects.
4. Impedance coatings on barriers.
5. Low barriers.
6. Pavement-barrier interaction.

These subjects are being investigated in a continuing phase of this research.

The report further points out a need for simplification of the models used in this study. Without revision they are too complex for routine use. Furthermore, the possibility of developing simple correction procedures that could improve the accuracy of the *Noise Barrier Design Handbook* is also noted. At the same time, the report identifies a need for extension of the models to cover realistic conditions created, for example, by atmospheric influences, irregular terrain, certain noise source characteristics, and barrier curvature. The researchers believe that an adequate basis of knowledge exists to deal with such questions, specifically with relation to highway noise modeling.

APPLICATIONS

The fact that the research findings have little immediate applicability to current problems has been noted earlier, and is not an unexpected result. Yet, even though the research has been based on a theoretical approach that calls for subsequent validation, certain findings do have interest to practitioners in the area of highway noise abatement. The report indicates the following three specific considerations that merit attention in barrier design.

Absorptive Coating. It has been shown that absorptive coatings are most effective in reducing diffraction when they are top coatings or otherwise are at near-grazing incidence. Furthermore, the greater the absorption coefficients in the frequency range of interest, the greater is the effect of the material, just as is the case, to a much greater degree, with the reduction of barrier reflection.

Multiple Shadowing. Although the advantages of multiple shadowing that have been reported will probably be found to be optimistic, it is not likely that they will be entirely discounted. The double wall, in particular, is a sufficiently simple construction that an experimental investigation of the feasibility of attaining the predicted benefits could well be worthwhile.

Cuts and Fills. These are wedge-like barriers, and, according to the findings, one or both sides must be impedance covered if the loss of attenuation due to large interior angles is to be offset. As suggested by the round-top wedge results, it is particularly useful to have impedance covering in the vicinity of the shoulder of the fill or the rims of the cut. When residential areas are just beyond the rim of the cut, it should be particularly helpful to have an impedance covering such as grass between them and the rim. If a wall is erected between the highway and the residences and if the cut is 10 ft (3 m) or more deep, an excellent opportunity exists to capitalize on the gains offered through double shadowing. To do so, the wall should be placed somewhat back from the rim rather than directly on it.

It is anticipated that a broader range of results applicable to barrier design problems will be derived after the next proposed phase of model validation is complete.

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2101 Constitution Avenue, N.W.
Washington, D.C. 20418