Determination of Traffic Noise Barrier Effectiveness: An Evaluation of Noise Abatement Measures Used on I-440

LLOYD HERMAN, WILLIAM BOWLBY, AND RAYMOND BRISSON

The noise abatement efforts used on I-440 were studied to evaluate their effectiveness. The results of tests confirmed that the FHWA abatement criterion for land use Category B receivers had not been exceeded at any of 40 representative sites. The Tennessee Department of Transportation criterion for substantial increase in levels at receivers due to new highway sources was exceeded at only 2 of 40 sites. Noise level reductions of as much as 9.5 dB at the receiver locations were attributed to depressing the roadway (cut) with the average being 2.8 dB. Of the sites tested, 75 percent realized at least a 5 dB reduction because of barriers alone (in addition to effect of cut, if any). The results of 24-hr measurement periods show the variation in traffic noise levels as well as background influences on levels and insertion loss determination. Comparison tests of absorptive and reflective barriers at two sites indicated that benefits were realized by the use of absorptive barriers on fill sections where barriers were installed close to shoulders. An evaluation of the FHWA STAMINA 2.0 model for highway traffic noise indicated that the model tended to predict levels higher than those measured. Insertion loss results were obtained using the ANSI S12.8 indirect predicted method of insertion loss determination. This method's dependence on the accuracy of the prediction model was seen as a limitation on its usefulness.

The highway traffic noise mitigation effort by the Tennessee Department of Transportation (TDOT) for I-440 has entailed one of the more ambitious abatement plans undertaken by a department of transportation. Large-scale excavation of limestone rock at considerable cost was required to depress most of the 7.2-mi roadway to provide the first step in noise reduction. This step was followed by the construction of a variety of noise barrier types [with a total length of 17.9 km (11.1 mi)] at an additional cost of $13.2 million. A total of 718 first-row residences along the 11.6-km (7.2-mi) project were protected at an average cost of $18,000 per residence for barriers alone.

The design of the noise barriers, which required modeling the entire length of I-440, was marked by both the complexity of the terrain and the multiplicity of abatement types. Furthermore, it included one of the largest analyses in this country of multiple reflections, both between noise barriers on opposite sides of the highway and between vertical rock faces in deep cut sections. The analysis resulted in the use of absorptive barriers for certain sections and modifications of barrier heights at other locations.

L. Herman and W. Bowlby, Vanderbilt University, Station B, Nashville, Tenn. 37235. R. Brisson, Tennessee Department of Transportation, Environmental Planning Office, 505 Deaderick Street, 900 James K. Polk Building, Nashville, Tenn. 37243-0334.

In the light of the extensive commitment that TDOT has made to noise mitigation for I-440, the decision was made to evaluate the effectiveness of the various abatement methods to determine the benefits realized. The evaluation was to be comprehensive in its treatment of all types of abatement used on I-440. The variety in types of terrain and the abatement methods used make the evaluation particularly useful for future projects in terms of the effectiveness of the various noise reduction measures and the accuracy of the design methods.

BACKGROUND

As early as 1957, the Tennessee Bureau of Highways held a public hearing on the location of the Interstate system in Nashville, which included the proposed I-440. This portion of the network was planned as an outer loop to improve crosstown transportation in the southern portion of Nashville. The proposed I-440 was planned to connect three legs of Nashville's urban Interstate system: I-40 West, I-65 South, and I-24 East. In 1964, FHWA approved a six-lane section of I-440 from I-40 West to I-65 South. Between 1968 and 1973 public hearings were held, and most of the right-of-way acquisition and relocation had taken place.

During this period the National Environmental Protection Act was enacted, but FHWA believed that because of the advanced stage of I-440, an environmental impact statement (EIS) was not required. However, as a result of a class action suit filed by the National Wildlife Federation against FHWA, the courts determined that an EIS was necessary for projects in which a substantial federal action remained. Further concerns from neighborhood groups were beginning to be expressed regarding the I-440 project. Many environmental concerns were expressed, especially about noise.

A protracted court battle over environmental issues was finally resolved in 1981 when the courts ruled that the project be built with a commitment from TDOT to minimize impacts. Two major revisions were (*a*) to reduce the number of lanes from six to four and (*b*) to change the basic profile from mostly at-grade or on-fill to mostly in-cut to reduce both noise levels and visual intrusion in neighboring communities. A major commitment was made to construct noise barriers wherever needed and feasible, and TDOT entered into an agreement with Vanderbilt University for analysis and design.

By early 1984, all of the I-440 project was under construction, with noise barriers included in the design along much of the project. The project opened to traffic in 1987.

RESEARCH OBJECTIVES

The evaluation process for the project included investigation of four issues: noise barrier effectiveness, changes in community noise levels due to I-440, effectiveness of sound absorptive walls, and differences between predictions and measurements.

Noise Barrier Effectiveness

Noise barrier insertion loss is the reduction in noise levels achieved by the insertion of a noise barrier between the noise source and a receiver of the noise. The insertion loss of a barrier is best determined by a direct before/after study: an existing, constant noise source is measured at a receiver position; the noise barrier is then built, and the noise level is measured at the same receiver position. If all conditions remain constant, the insertion loss would be the difference between the before- and after-construction noise levels. However, in highway applications, both the noise source and the surrounding conditions are changing. In the case of I-440, the highway noise source did not exist before construction of the noise barriers. Therefore, other methods of insertion loss determination must be used, such as measuring at equivalent "before" sites or predicting the before levels.

Whereas barrier performance is typically described in terms of insertion loss, the insertion loss of a barrier is a varying value. The insertion loss of a barrier varies depending on the distance of the receiver from the barrier, the distance of the barrier from the source, the height of the source, traffic flow, weather conditions, and so forth. Unlike a physical characteristic of a noise barrier, such as the density of its material, the insertion loss is not an intrinsic property. Therefore, the objective was to determine insertion losses for the barriers under typical conditions for the 40 receivers studied, which represented a subset of all possible receivers.

Once the determination of noise barrier insertion loss was made, the results were to be considered from the four following viewpoints:

- Determine the range of effectiveness for each noise abatement type. A number of noise abatement methods were used on I-440, including reflective and absorptive noise walls, natural barriers, berms, and retaining walls. In addition, the various abatement types were constructed in varying terrain, involving cuts, fills, and at-grade conditions. Whereas these methods were not used in equal amounts, they were to be categorized for comparison to determine the relative effectiveness of each type. TDOT could then use this information on future projects. All noise abatement methods used on I-440 were placed in one of the following four categories: noise wall at grade, noise wall on fill, depressed section (cut) plus noise wall, and depressed section (cut) plus berm.
- Compare noise barrier performance with design goals (predicted performance). The comparison was designed to determine how closely the performance of the noise abatement method matched the predictions of the model in the original acoustical design of the barriers and the general TDOT goal of a 5- to 10-dB noise reduction.
- Determine the overall amount of noise reduction achieved for residences. Using the insertion loss information, the amount of noise reduction that was experienced at the residences distributed along I-440 was to be characterized.
- Compare the performance of FHWA STAMINA 2.0 (*1,2*), which was used in the barrier design, with field measurements. By measuring the actual barrier performance, the ability of STAMINA to accurately predict the results could be evaluated. The purpose of the evaluation was to provide input for future noise barrier performance predictions for TDOT.

Changes in Community Noise Levels due to I-440

Despite the various methods of noise abatement used to reduce the highway traffic noise, I-440 represents a new noise source to its neighbors. Thus, even though attenuated, the I-440 noise is heard and may be thought undesirable by some people. The changes in community noise levels due to the construction of I-440 were to be quantified using two methods:

1 Before construction of I-440, TDOT had made extensive measurements to determine the sound levels in the community around the proposed location. These levels, without the highway, were used in this study for comparison with the levels measured behind the barriers at the 40 sites being studied to determine the increase in community levels at the current time. As a further step, the measured existing noise levels were to be compared with established FHWA noise impact and abatement criteria to gain insight as to how the community is being affected.

2. A second concern relates to possible changes in barrier effectiveness or community noise levels over time with future growth of traffic on I-440. A site was to be selected for monitoring long-term effects. The measurements at this site would be made for 24-hr periods and would be repeated in the future, perhaps annually. The 24-hr measurement would provide information relating to both the actual levels and insertion loss changes occurring for day and night periods. In addition, the repeated annual measurements would provide insight into changes occurring in the long term. The objective for this study included both the site selection and the first in a series of 24-hr data collection periods.

Effectiveness of Sound Absorptive Walls

Sound absorptive walls were installed along certain sections of I-440 to overcome multiple sound reflection problems between parallel reflective walls. The materials used represented an innovative application for traffic noise control; however, no data are available on their actual performance. This objective included not only a study of the insertion loss at residential sites in the sections using absorptive barriers, but also a more detailed comparison of the change in insertion loss in each sound frequency band as a result of using absorptive materials and reflective materials.

Differences Between Predictions and Measurements

Differences between the predicted barrier performance and the measured results were anticipated. To provide insight for future designs, an analysis of these differences was to be undertaken. An investigation of each site where a discrepancy might occur was to be made. The reasons for the discrepancy were to be categorized under three major areas: acoustical analysis concerns, physical design issues, and construction problems. The reasons for the differences between the predicted and measured barrier performance were to be studied and a series of recommendations developed to improve the noise barrier analysis design and construction process for future TDOT projects.

RESEARCH AND RESULTS

To accomplish the preceding objectives, 40 representative sites were selected for noise measurements. Before noise measurements were made, an emissions testing program was undertaken for the traffic and roadway conditions specific to I-440. The amount of noise emitted by a particular class of vehicle for the road surface on which it is operating was described statistically. The results of this testing shown in Figure 1 indicated that two of three vehicle classes, automobiles and heavy trucks, were different from those previously determined by FHWA on a national basis (automobiles about 4 dB higher than national average and heavy trucks 1 dB lower). These new values were used in the noise model predictions that were principal elements in the evaluation of the noise abatement methods. The information taken at each study site included the sound levels typically experienced by a given residence as well as the traffic conditions occurring at the time of the measurements. The combined data from site testing, vehicle noise emissions testing, and computer prediction modeling were analyzed to produce the following results.

The effect of depressing the roadways (cut sections) was to reduce the 1-hr average sound levels L_{eq} for residences by as much as 9.5 dB with an average of 2.8 dB. The amount experienced at a given site was generally proportional to the amount that the roadway was depressed. In addition to the depressed roadway section method of noise abatement, noise walls or berms were also effective in further reducing the sound levels. The results are shown in Figure 2. The determination of the insertion loss for the walls or berms alone was based on the difference between the measured after levels with the barriers in place and the predicted before levels. The predicted before levels included the effect of any natural barriers such as the side slopes of depressed sections. As shown in Figure 3, at least a 5-dB reduction (L_{eq}) due to the noise barriers alone was realized by 75 percent of all the sites tested, including those not depressed. The overall noise reduction achieved by the combination of depressing the roadways and constructing barriers reduced the levels by an average of 11.5 dB (see Figure 2).

Whereas the preceding results are indicative of the performance of the noise abatement measures tested, the overall results of these measures were judged by two other methods. The first method of determining the impact of a new noise source was to quantify the change in sound levels experienced at a given residence (i.e., from before construction to after construction with the new source) and compare the changes with established criteria. The TDOT criteria for impact are as follows: 0 to 5 dB, no impact; 6 to 15 dB, moderate impact; and greater than 15 dB, substantial impact. A design goal for all residences on I-440 was to limit impact to the moderate category. As shown in Figure 4, only two sites increased in levels enough to be considered substantially affected. These

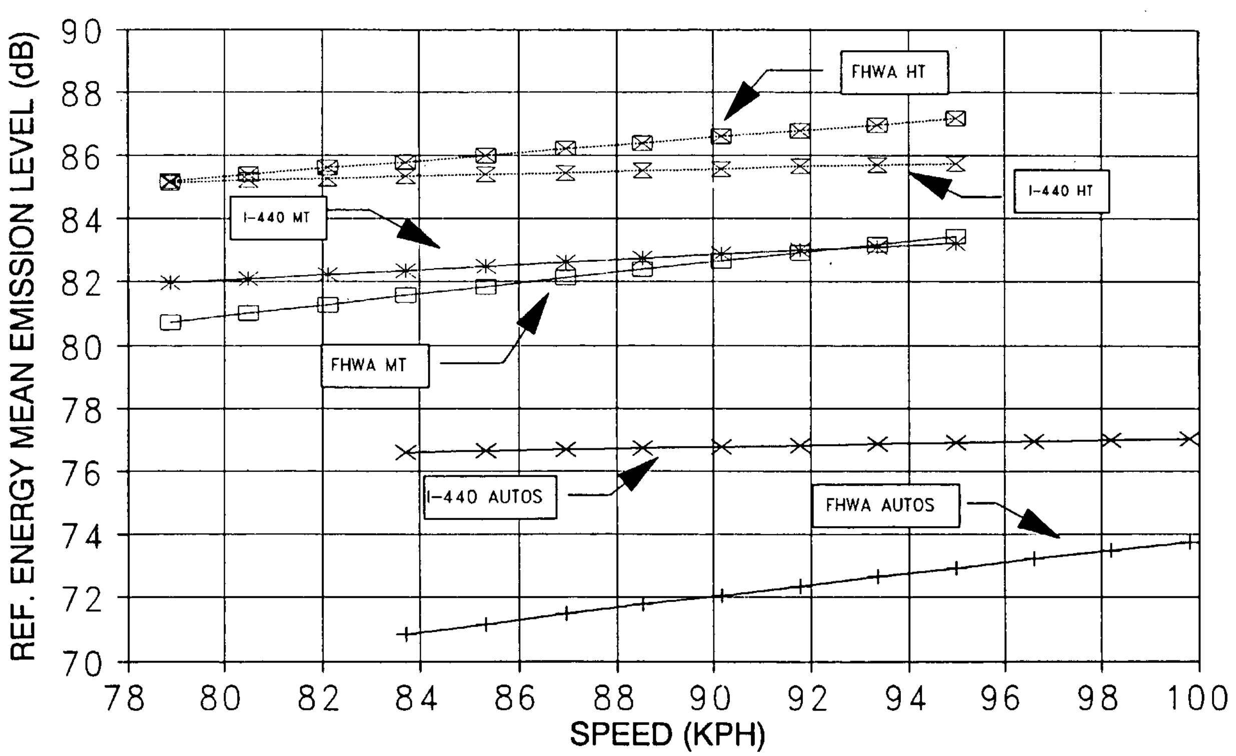

FIGURE 1 Comparison of I-440 and FHWA reference energy mean emission levels.

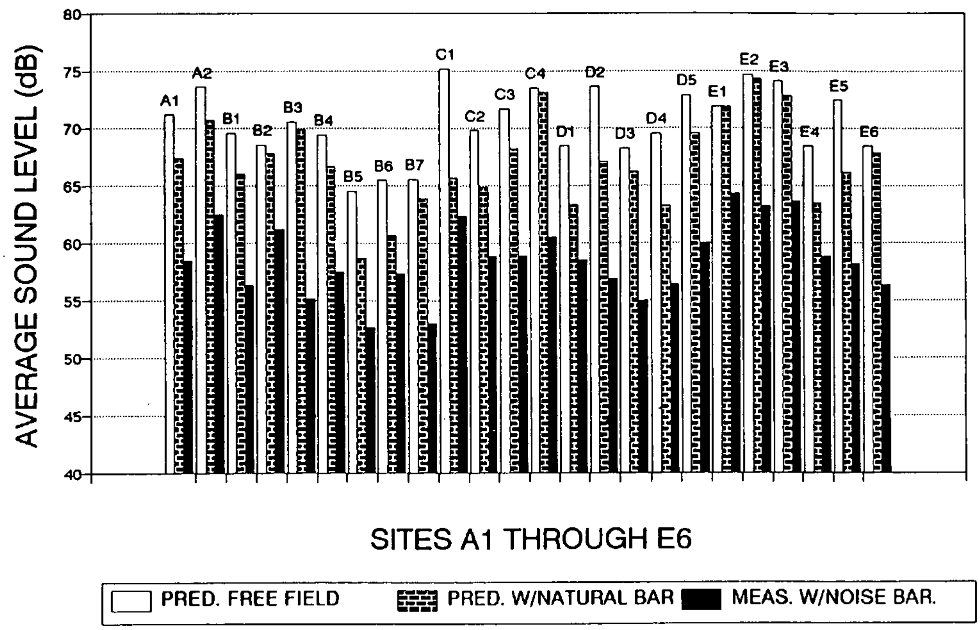

FIGURE 2 Overall insertion loss (depressed roadway and barriers), Sites A1 through E6.

two sites, however, began with the some of the lowest preproject levels recorded (see levels shown in Figure 5). These levels were so low that the addition of the new highway noise source had a greater effect than at other sites with higher preproject levels. Furthermore, site E1, which experienced a level of 64 dB, was located on a knoll, thus reducing the effectiveness of the barrier compared with adjacent residences. This comparison was based on the L_{10} descriptor (the level exceeded for 10 percent of the measurement period, which was used by TDOT in its preproject measurements).

The second method used to judge the overall effectiveness of the noise abatement measures was to compare the noise levels at the measurement sites with a benchmark or reference level. The benchmark chosen for this project was the FHWA abatement criteria. These criteria are not design goals. However, if predicted project levels without abatement had been below the criteria, the impact of the project would not have been judged serious enough (by these criteria alone) to warrant consideration of abatement. The FHWA criterion for Activity Category B receivers, the relevant category for the sites studied, is an L_{10} of 70 dB (or an L_{eq} of 67 dB). The FHWA noise standards state that abatement must be considered for those receivers in Category B in which levels "approach or exceed" an L_{10} of 70 dB or an L_{eq} of 67 dB.

The comparison of the levels at the individual sites with the FHWA criterion shown in Figure 5 supports the success of the abatement efforts. Regardless of the specific abatement measure or combination of measures used for a particular

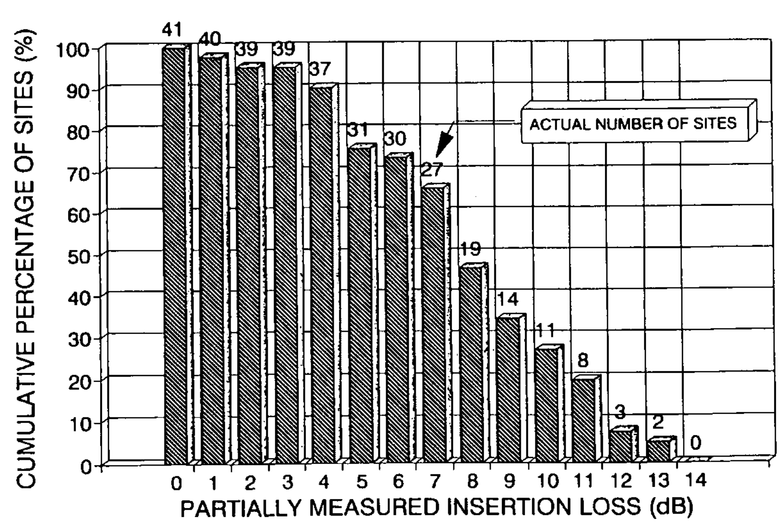

FIGURE 3 Percentage of sites equaling or exceeding a given partially measured insertion loss.

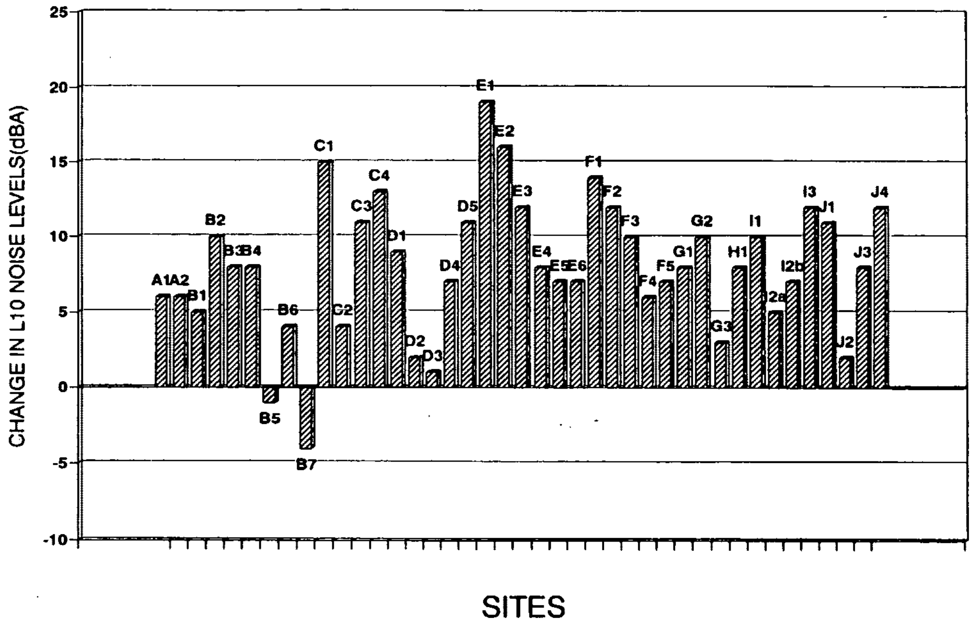

FIGURE 4 **Change in community noise levels due to I-440 construction.**

site, the net result is that not one of the sites measured "approached or exceeded" the FHWA criterion (all were 4 dB or more below the L_{10} of 70 dBA and 2 dB or more below the L_{eq} of 67 dBA). In other words, the levels for every site tested were below this reference level.

Noise barriers that reduce reflected noise through the use of sound-absorbing materials had been constructed on certain fill sections of I-440. A detailed investigation of the effectiveness of these barriers was accomplished by comparing the levels behind the absorptive barriers with those at the adjacent reflective barriers used on bridge overpasses. Because of the number of interrelated factors affecting the measured levels, however, the effect of the absorptive barriers could not be completely isolated. The measured levels at the absorptive barrier sections were lower than the levels at the adjacent reflective metal walls. Whereas several other influences were present in these levels, as detailed in the project report, the absorptive barriers were found to be effective in reducing wall

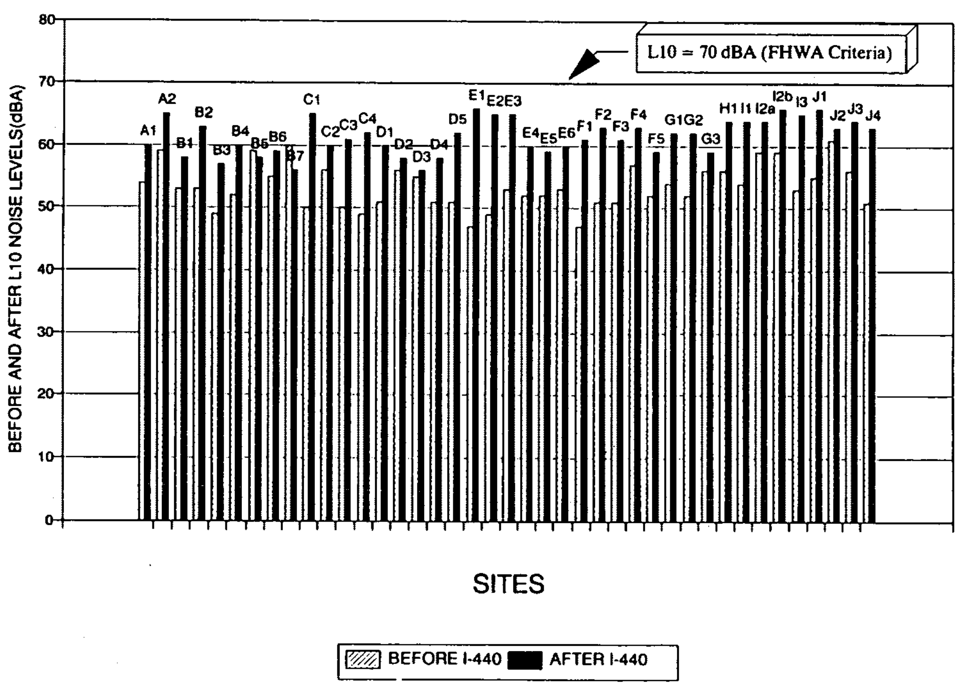

FIGURE 5 **Change in community noise levels and comparison with FHWA criteria.**

heights for situations where the barriers are located close to roadway shoulders and sound reflections are likely to occur.

Measurement periods of 24 hr were conducted at one site to determine the changes in levels and insertion loss experienced throughout the day. The change in levels for the four microphones (two reference, two study) is shown in Figure 6. The two sites included in this comparison involved a section with a noise barrier and a section without a noise barrier. The sites were adjacent at a depressed section of the roadway. They were judged to be very close in terms of terrain equivalence. Whereas only the second 24-hr period is shown in Figure 6, the hour-by-hour levels for the first 24-hr period were remarkably close to the second period, indicating consistent day-to-day traffic patterns on I-440. The insertion loss produced by the barrier is represented by the difference in levels between the study microphones (adjusted for differences in the levels at the reference microphones). The measurements were made simultaneously; therefore, the reference microphone levels essentially canceled for the standard insertion loss calculation.

The large variation in "with barrier" and "no barrier" levels, centered on 3:00 a.m. in Figure 6, was studied subsequent to the initial measurements and data reduction. The tape-recorded samples indicated that the levels at the "no barrier" study microphone site were elevated by insect noise. In effect, the insertion loss computed from these data is a lower bound, since the traffic noise level at the "no barrier" study microphone is masked. This observation emphasizes the importance of background considerations for true insertion loss determination.

A detailed investigation of the FHWA STAMINA 2.0 prediction model was undertaken. It was concluded that the model tends to predict sound levels somewhat higher than those actually measured, as shown in Figure 7.

In addition to the inaccuracies introduced by the prediction model, construction differences were considered. Barrier heights that were measured at every site tested proved to be consistent with design specifications. The results of these measurements indicate that the wall heights were indeed as planned. However, a median berm was added to the project after the acoustical planning stage. The median berm was calculated to have reduced sound levels by approximately 0.5 dB for the unshielded reference microphone location at the barrier, depending on the overall cross-sectional configuration. An even greater reduction would be projected for residential receivers.

CONCLUSIONS

Among the conclusions of the study of the I-440 noise abatement methods were the following:

- The noise abatement efforts used on I-440 were successful considered in light of both the FHWA criteria for noise abatement and the TDOT criteria for substantial increases in noise levels over levels before highway construction.
- The FHWA STAMINA 2.0 model could benefit by enhancements to more accurately predict noise levels. It is recommended that the research be supported and actively followed for an upcoming FHWA project that will develop a STAMINA 3.0 model. A statewide survey of the reference energy mean emission levels of its vehicles with attention to the full range of travel speeds and pavement types should be performed.
- To monitor long-term changes in sound levels due to traffic noise as well as the corresponding performance of noise abatement methods, the 24-hr measurements should be continued with annual measurements at the same site.
- When noise is anticipated to be a problem, depressing future highways and using median berms should be considered where possible. Whereas the single or combined effects of

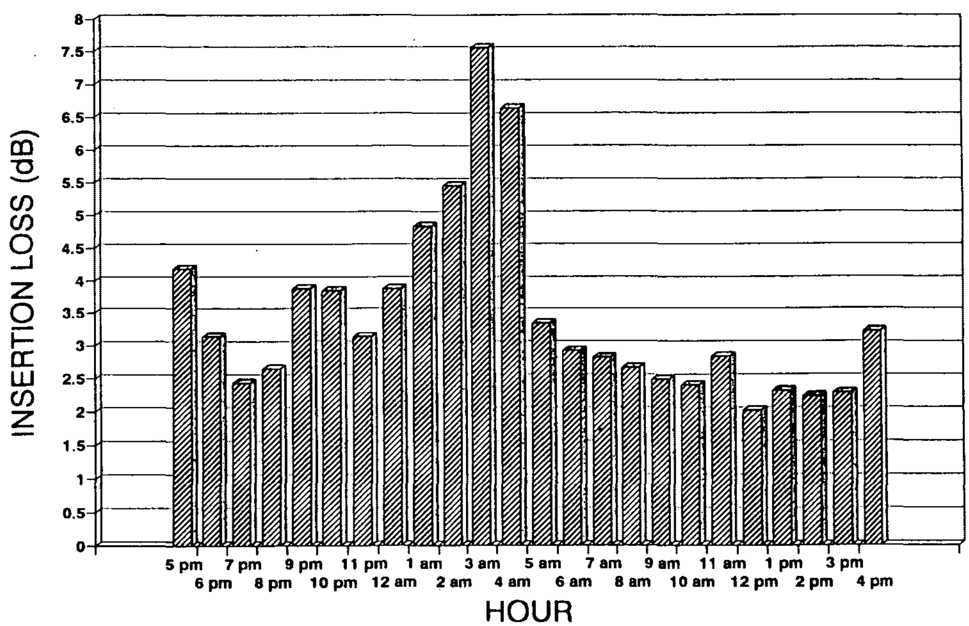

FIGURE 6 Hourly average insertion loss, 24-hr site, second 24-hr period, August 14–15, 1991.

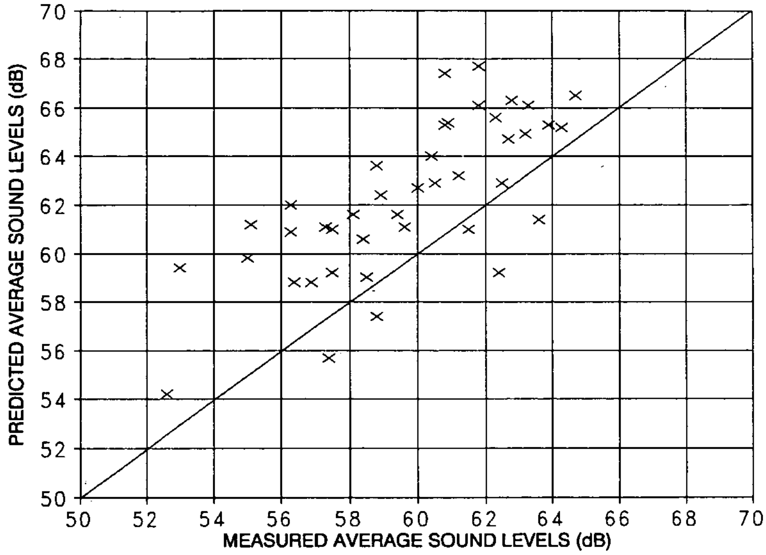

FIGURE 7 Comparison of measured and predicted levels: study microphone.

either of these methods alone will generally not be adequate, they contribute to the overall noise reduction when coupled with the construction of noise walls or berms.

- Noise abatement committees should be established for each abatement project. The committees should include representatives from planning, design, structures, construction, maintenance, and landscape architecture. This team concept, which is used effectively in other states, helps to ensure continuity in the abatement project development process and to identify and resolve concerns or problems early in the process.

REFERENCES

1. Menge, C. W. *User's Manual: Barrier Cost Reduction Procedure, STAMINA 2.0 and OPTIMA.* Interim Report. FHWA, U.S. Department of Transportation, June 1981.
2. Bowlby, W., J. Higgins, and J. A. Reagan. *Noise Barrier Cost Reduction Procedure, STAMINA 2.0/OPTIMA: User's Manual.* Report FHWA-DP-58-1. FHWA, U.S. Department of Transportation, Arlington, Va., 1982.

Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.