FIELD EVALUATION OF TRAFFIC NOISE REDUCTION MEASURES

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As part of a continuing research program, approximately 400 acoustic noise records plus supporting traffic and environmental data were acquired in the vicinity of six highway sites representing four types of traffic noise reduction measures: roadside barriers, elevated highways, depressed highways, and roadside structures. The ultimate goal of the noise surveys was to validate or modify as required the noise reduction prediction procedures outlined in NCHRP Report 117 (1). To this end, the traffic noise data were converted to noise reductions at specific locations in terms of A-weighted L_{50} (median) sound pressure levels and then compared to the predicted noise reductions. Agreement was assessed in terms of the least squares line for the measured versus predicted noise reductions and the average discrepancy between the measured and predicted results as a function of the receiver distance from the roadside and height above the ground. The results indicate that the best agreement between the predicted and measured data is provided by the elevated highway and roadside structures configurations. For the roadside barrier and depressed highway configurations, the procedures of NCHRP Report 117 appear to underpredict the noise reductions at those locations where there is nearly a direct line of sight to the traffic flow. Based on these results, modifications to the noise reduction curves in NCHRP Report 117 are derived and presented.

•TRAFFIC noise generated on modern highways is a major source of environmental noise pollution. Urgent needs exist not only for realistic highway noise standards but also for engineering tools that can be implemented by highway designers to control this form of noise pollution. In a previous study published by the Highway Research Board, systematic procedures for the calculation of highway noise levels were presented in the form of a design guide for highway noise prediction (1), hereafter referred to as the "design guide." The methods suggested in the design guide represent an important step toward the solution of traffic noise problems in that they allow a highway engineer to predict the expected noise levels for particular highway configurations and to assess the changes in noise levels due to modifications of highway geometry. However, the design guide methods were based in part on theoretical model studies involving many simplifying assumptions, particularly in the calculation procedures for the amount of noise reduction provided by various highway noise control measures.

Several theoretical and empirical methods have previously been proposed for estimating how barriers reduce the sound level from a point source (2-7). Of course, the applicability of these methods to field situations is somewhat questionable because an actual highway entails a source that is distributed over the roadway geometry. In developing the design guide, a limited field measurement program was conducted to evaluate previous theoretical prediction procedures and to modify them as required to account for an extended noise source. More recently, a further refined model for predicting barrier noise reductions has been suggested (8) where the noise source is

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modified to represent an incoherent line source. Nevertheless, the potential of various highway noise reduction measures under actual traffic and environmental conditions remains only partially understood.

In recognition of this fact, a study was initiated by the Highway Research Board with the following objectives:

1. Review and analyze the present state of the art in the prediction of acoustic performance for various highway noise reduction measures including roadside barriers, elevated highway sections, depressed highway sections, and roadside structures;
2. Locate operational examples of typical constructions and conduct a data acquisition program to collect field noise reduction measurements;
3. Interpret the field data in terms of the parameters that modify the noise reduction effectiveness of each construction;
4. Relate the preceding information to current prediction techniques and validate or modify the current procedures presented in the design guide; and
5. Prepare, when appropriate, corrected noise prediction procedures for the various constructions in a form that can be incorporated into the design guide.

The approach pursued in this recently completed study, along with the general results, is summarized in this paper.

APPROACH

The initial task was to define, locate, and select the basic geometries to be evaluated. After an intensive search of existing configurations throughout the country, six test sites were selected for acoustical evaluation as follows:

1. Site 1—a roadside barrier configuration along a section of I-680 in Milpitas, California;
2. Site 2—an elevated highway configuration along a section of US-101 (Ventura Freeway) in Encino, California;
3. Site 3—an elevated highway configuration along a section of I-405 (San Diego Freeway) in Van Nuys, California;
4. Site 5—a roadside structures configuration along a section of I-35W in Richfield, Minnesota;
5. Site 6—a roadside structures configuration along a section of I-94 in Ypsilanti, Michigan; and
6. Site 9—a depressed highway configuration along a section of I-35W in Minneapolis, Minnesota.

The next task was to design a measurement program for each test site capable of collecting data to provide an adequate site description in acoustic terms. This was followed by the data acquisition program in which the sites were acoustically surveyed. The basic information collected during the data acquisition program was as follows:

1. Noise levels—Ten-min tape recordings were made of the noise levels at each of numerous different positions located various distances from the highway and above the ground. Figure 1 shows an outline of the measurement locations at site 2. Note that, during the recording of noise levels at all shielded locations (stations B, C, and D, Fig. 1), a noise measurement was simultaneously recorded at a free field location (station a, Fig. 1) for reference purposes.
2. Traffic conditions—Average traffic volume (vehicles per hour), speed, and truck-automobile mix were determined during the 10-min noise measurement runs. Photographic techniques were used to record these parameters.
3. Environmental conditions—Wind velocity and direction, temperature, and relative humidity were measured at the start of most measurement runs.

Note that the goal was to obtain noise measurements under a wide range of traffic and environmental conditions. However, the data collected were necessarily confined to the actual conditions found at each site.

The third task was the reduction of the field recordings into meaningful measures of acoustic noise. This was done by first reducing each 10-min data record in terms of the A-weighted sound pressure level as a function of time. The A-weighted levels were then passed through a statistical distribution analyzer to obtain the sample distribution function of the levels over the 10-min measurement run. Figure 2 shows the statistical distributions for selected measurement runs at site 2. These statistical distributions were then fitted by a normal distribution, and the L_{50} and L_{10} levels were computed from the normal approximation.

The final task was the evaluation of the data. The L_{50} (median) levels computed from the measurements at each test site were used for the evaluation in most cases. Specifically, the basic L_{50} noise data were converted to excess noise reductions at various locations (distances from the roadside and heights above the ground) by subtracting the shielded L_{50} levels from the free field L_{50} levels. The free field L_{50} levels at the shielded locations were estimated by extrapolating the L_{50} levels measured at the unshielded reference location (station A) based on the modified line source distance attenuation rule used in the design guide (4.5-dB decrease per doubling of distance).

EVALUATION PROCEDURES

The noise reductions predicted by the design guide, as well as other prediction procedures of interest, were computed at each location where measurements were obtained. This provided a direct comparison of the measured and predicted noise reductions at each measurement location for each site. The agreement between the measurements and predictions was evaluated by computing various statistical parameters as follows:

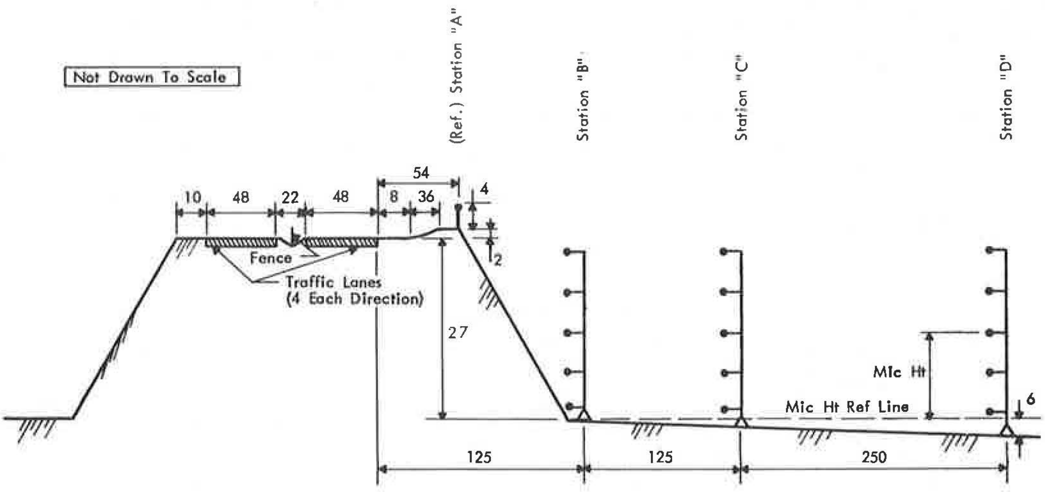
1. Average discrepancy between the measured and predicted noise reductions (discrepancy Δ = predicted value minus measured value);
2. Standard deviation of the discrepancy between the measured and predicted noise reductions;
3. Least squares line for measured versus predicted noise reductions;
4. Average discrepancy between the measured and predicted noise reductions versus distance from the roadside, computed by averaging the discrepancies over all heights at each distance; and
5. Average discrepancy between the measured and predicted noise reductions versus height above the ground, computed by averaging the discrepancies over all distances at each height.

The first two parameters constitute estimates of the overall bias error and random error respectively in the predictions relative to the measurements. The third parameter, the least squares line, provides an indication of the agreement between the measurements and predictions as a function of the magnitude of the predicted noise reduction. The last two parameters indicate the accuracy of the predictions as a function of the observer location in terms of distance from the roadside and height above the ground respectively. In all cases, the computed values of the parameters in question were tested for a statistically significant difference from zero at the 1 percent level of significance by conventional statistical testing procedures (9).

As an illustration of the evaluation procedure, the detailed results for the comparison of the measured noise reduction data at site 2 (as shown in Fig. 1) versus the noise reductions predicted by the design guide procedures are given in Table 1 and Figures 3 and 4. During the measurement runs at this site, the average traffic volume was 10,000 to 14,000 vehicles per hour (heavy), the average traffic speed was 50 to 60 mph, and the truck-automobile mix was 2 to 6 percent. The environmental conditions included a southeasterly wind of less than 8 mph, temperatures ranging from 62 to 85 F, and a relative humidity of 40 to 90 percent.

The predicted noise reductions were computed to be an average of 1.33 dBA higher than the measured noise reductions (Table 1). In other words, the design guide procedure appears to be slightly biased toward overprediction for this case. There is also a random error (scatter) between the measured and predicted results as indicated by the standard deviation of 2.33 dBA in the discrepancies. The least squares line for the measured versus predicted noise reductions suggests that the tendency toward overprediction occurs primarily at the 5-to-10-dBA noise reduction level, as shown

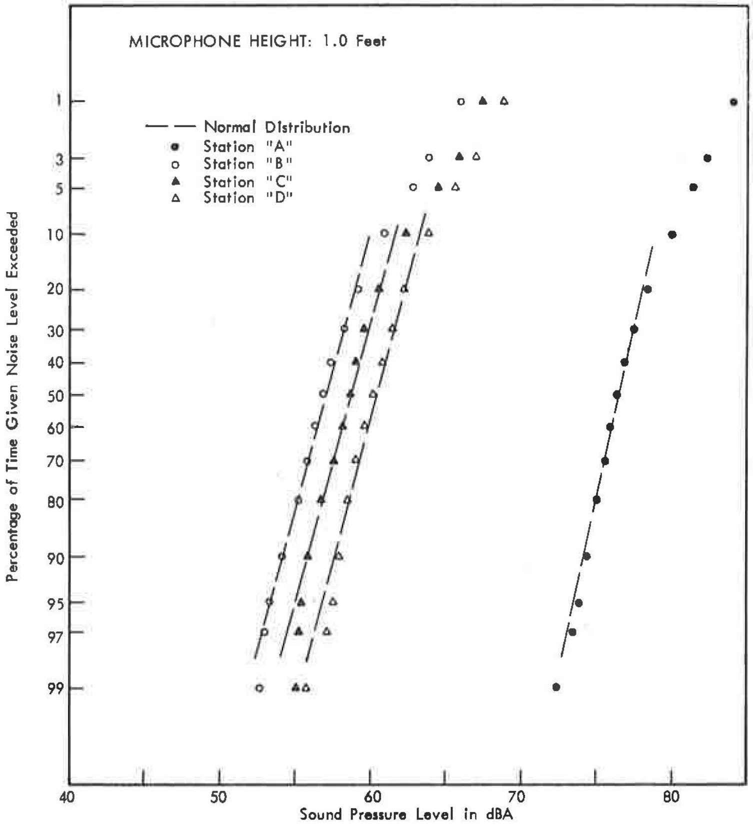
Figure 1. Cross section and acoustic measurement stations for site 2.



Station	Mic Heights (ft.)
A	33
B	1, 5, 10, 15, 20
C	1, 5, 10, 15, 20
D	1, 5, 10, 15, 20

ELEVATED HIGHWAY CONFIGURATION

Figure 2. Cumulative distribution curves for site 2.



in Figure 3. There is no significant variation in the discrepancy at various distances from the roadside. There is, however, a small but statistically significant variation in the discrepancy at various heights above the ground, as shown in Figure 4b.

The foregoing type of evaluation was applied to the measured noise reductions at all six sites in comparison to the predictions afforded by several procedures, including the design guide (1), a modified line source model, and, in some cases, the point and line source models of Maekawa (2, 3) and Kurtz and Anderson (8) respectively. A summary of the basic noise reduction curves for these various models is shown in Figure 5. Other evaluations included studies of possible variations in the discrepancy between measured and predicted noise reductions as a function of traffic volume, traffic speed, truck-automobile mix, wind, and air temperature.

SUMMARY OF RESULTS

A summary of results of the comparisons of the measured noise reductions and the design guide predictions for all six sites are given in Table 2. Note that, for convenience and direct comparability of results, the design guide model curve of Figure 5 was used to predict the noise reductions for the elevated and depressed highway sites as well as for the roadside barrier site. The actual curves in the design guide, when converted to the format of Figure 5, differ slightly from this model for the case of elevated and depressed highway configurations.

Reasonably good agreement is achieved between the measured and predicted noise reductions for the elevated highway configuration (Table 2). For the two sites (sites 2 and 3) with this configuration, the average difference between the measurements and predictions is less than 1.4 dBA. Furthermore, the variation in the prediction accuracy is negligible with distance from the roadside. On the other hand, the data suggest a significant variation with distance above the ground, and the least squares lines, when investigated together in detail, indicate a tendency to overpredict at points of intermediate noise reduction (5 to 10 dBA) and underpredict at points of very low noise reduction (less than 3 dBA).

The results for the roadside structures cases (sites 5 and 6) reveal surprisingly good agreement considering the simplicity of the design guide procedure for this configuration (5 dBA of noise reduction per row of structures to a maximum of 15 dBA). There is, however, a tendency toward underprediction for a single row of structures and overprediction for three rows of structures.

The poorest agreement between the measured and predicted noise reductions occurs for the roadside barrier and depressed highway configurations. In both cases, the results indicate a strong tendency for the design guide precedures to underpredict, by an average of 5 or 6 dBA, the noise reductions at locations associated with small values of the path-length difference parameter δ (Fig. 5 gives a definition of δ). This leads to the clear suggestion that a noise reduction model more like that proposed by Maekawa or Kurtz and Anderson (Fig. 5) would provide better agreement. Indeed, when the data in terms of L_{10} levels for the roadside barrier site were evaluated in comparison to the predictions provided by the Maekawa curve, no significant differences were found between the measured and predicted results in any of the categories given in Table 2.

Further studies of the agreement between the measured and predicted noise reductions as a function of various traffic and environmental factors indicated no significant variations in the agreement for variations in traffic volume, traffic speed, truck-automobile traffic mix, wind, and air temperature. However, the range of values for the dependent variable in many of these cases was not sufficient to make the results conclusive. For example, measurements were rarely made when wind velocities were greater than 8 mph because of the potential problem of wind noise at the measurement microphones. When this is coupled with the fact that most measurements were made within 250 ft of the source, it is not surprising that no significant influence of wind could be identified in the data. There is little question in practice that wind can, under certain conditions, have a strong influence on apparent noise reductions, particularly at locations upwind from the source (10).

Table 1. Results of design guide predictions for site 2.

Statistical Parameter	Computed Results	Ideal Results	Statistical Significance[a]
Average discrepancy, $\overline{\Delta}$ ($\Delta = x - y$)[b]	1.33 dBA	0	Yes
Standard deviation, s_Δ	2.33 dBA	0	Yes
Least squares line[b] (Fig. 3)	y = -2.76, +1.18x	y = x	Yes
Range of $\overline{\Delta}$ with distance from roadside (Fig. 4a)	1.7 dBA	0	No
Range of $\overline{\Delta}$ with distance above ground (Fig. 4b)	2.5 dBA	0	Yes

Note: Sample size was 47.

[a] All difference tests performed at 1 percent level of significance.
[b] x = predicted noise reduction; y = measured noise reduction.

Figure 3. Measured versus predicted noise reductions for site 2 using design guide predictions.

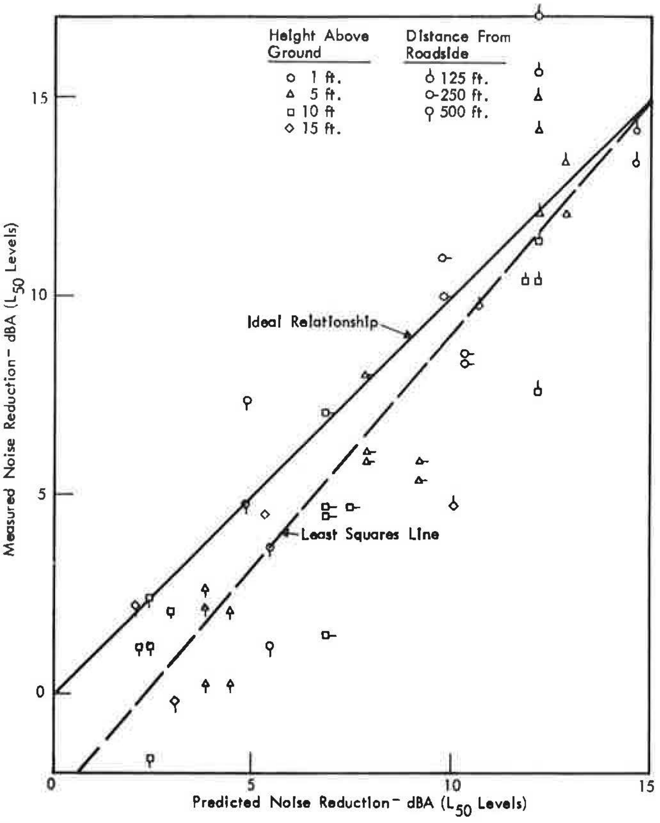


Figure 4. Discrepancy between measured and predicted noise reduction versus location for site 2 using design guide predictions.

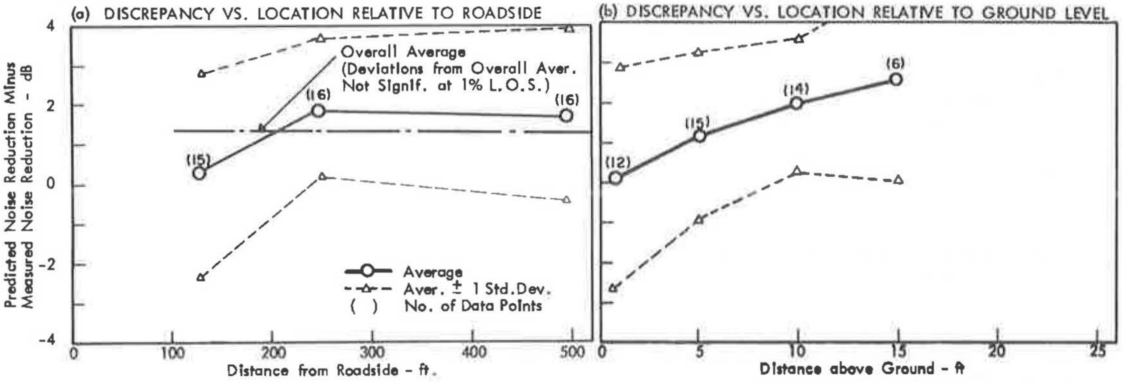


Figure 5. Attenuation of infinite acoustic barrier for point source and infinite line source.

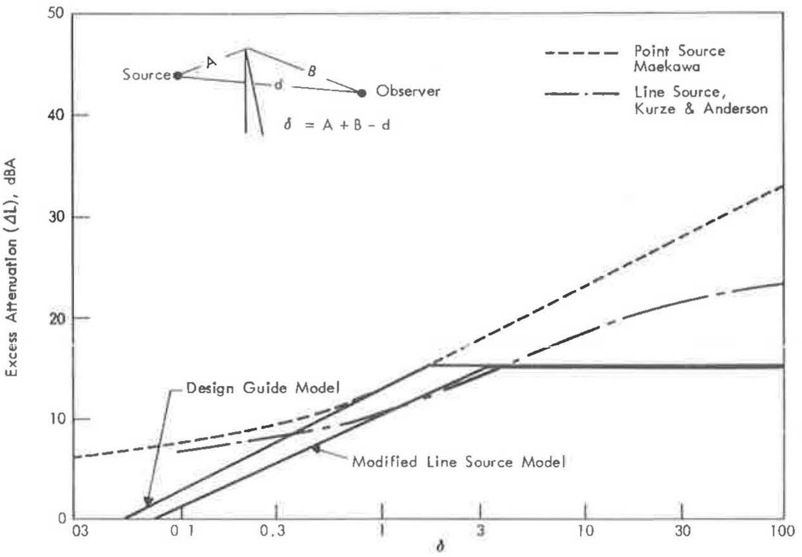


Table 2. Results of design guide predictions for all sites.

Statistical Parameter	Measurement Site 1 (roadside barrier)	2 (elevated highway)	3 (elevated highway)	5 (roadside structures)	6 (roadside structures)	9 (depressed highway)
Sample size, n	59	47	54	12	18	59
Average discrepancy, $\overline{\Delta}$	-1.67 dBA	1.33 dBA	0[a]	0[a]	0[a]	-3.04 dBA
Standard deviation, s_Δ	2.87 dBA	2.33 dBA	2.78	1.95 dBA	3.18 dBA	2.96 dBA
Least squares line	y = 6.76, +0.50x	y = -2.76, +1.18x	y = 1.60, +0.44x	—[b]	—[b]	y = 3.04, +1.00x
Range of $\overline{\Delta}$ with distance from roadside	3.4 dBA	0[a]	0[a]	0[a]	6.0 dBA	2.9 dBA
Range of $\overline{\Delta}$ with distance above ground	6.6 dBA	2.5 dBA	5.5 dBA	—[b]	—[b]	4.7 dBA

[a] Computed values not significantly different from zero (or y = x) at 1 percent level of significance. [b] Insufficient data for meaningful calculations.

Figure 6. Adjustment for roadside barriers.

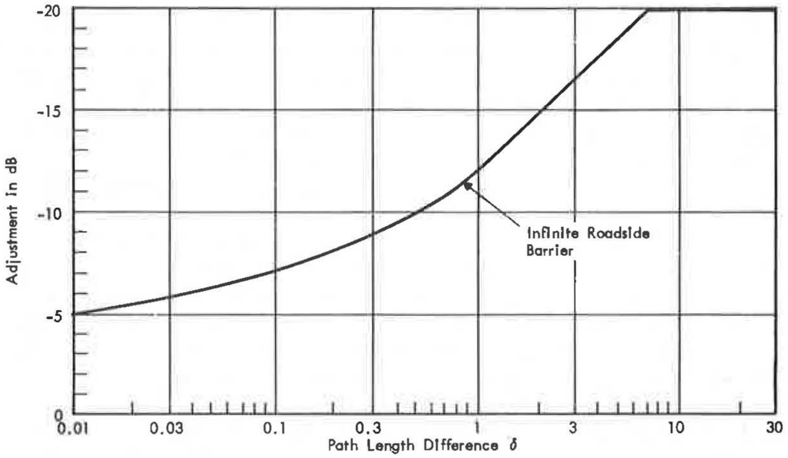
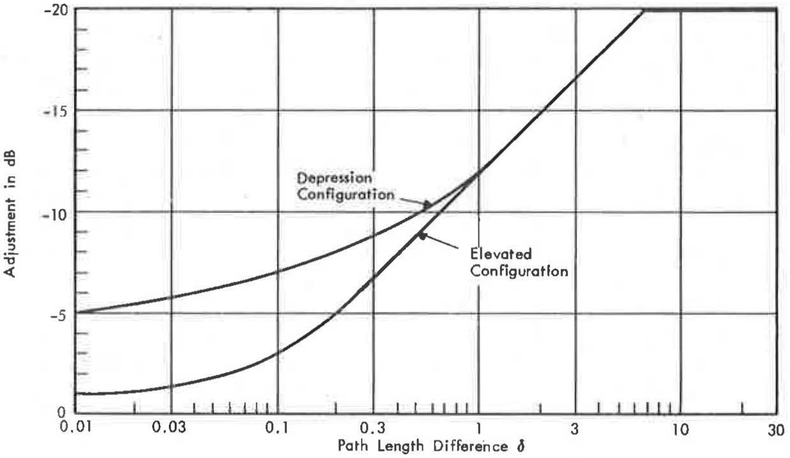


Figure 7. Adjustment for elevated and depressed roadway configurations.



CONCLUSIONS

The results of the study indicate that some modifications of the prediction procedures presented in the design guide (1) are in order. Specifically, it is recommended that the basic noise reduction curves for roadside barriers be changed to that shown in Figure 6 and, for elevated and depressed highway configurations, to those shown in Figure 7. It is further recommended that the procedure for estimating the noise reduction due to roadside structures be altered to specify 4.5 dBA of noise reduction for the first row of structures plus 1.5 dBA for each additional row of structures to a maximum of 10 dBA of reduction.

These recommended changes can be incorporated into the design guide without major alterations or complications of the current overall procedure. It should be mentioned that more precise noise reduction predictions might be achieved by major modifications of the design guide procedure, particularly as it deals with the truck-automobile noise reduction problem. However, it is not believed that the increased complexity of such procedures would be justified by the limited potential improvement in the final results provided by applications of the design guide to highway design problems.

Beyond the direct conclusions relating to the design guide procedures, two peripheral conclusions that suggest areas for future research resulted from this study. The recommended noise reduction curve for roadside barriers (Fig. 6) is very similar to the analytical line source model suggested by Kurtz and Anderson, as shown in Figure 5. It is believed that the exact Kurtz and Anderson model might provide an excellent fit to the data if it were not for the difference in source heights between trucks and automobiles. Specifically, from the viewpoint of a distant observer, automobile noise appears to radiate from a point near ground level (primarily tire noise), whereas truck noise often includes major contributions from the exhaust stack that extends well above ground level. A difference of several feet in source height can make a significant difference in the path-length difference parameter δ and hence in the effective noise reduction provided by a barrier. The design guide deals with this problem by simply estimating the noise reduction for trucks as 5 dBA less than the noise reduction computed assuming a source at ground level. More research on the basic characteristics and mechanisms of truck noise generation is needed before improved procedures for predicting the reduction of truck noise by barriers can be formulated.

The second peripheral conclusion evolves from the difference between the measured noise reductions for roadside barrier and depressed highway configurations and the elevated highway configuration, as indicated by the recommended noise reduction curves shown in Figures 6 and 7. Specifically, the data acquired during this study support the conclusion that roadside barriers and depressed highway configurations provide noise reductions at small values of path-length difference similar to the predictions of Maekawa or Kurtz and Anderson (Fig. 5). However, the data for the elevated highway sites do not correspond in that significantly lower noise reductions at small values of path-length difference were measured. The reason for this difference between the roadside barrier and depressed highway configurations and the elevated highway configuration is not clear, but it might be due to the directivity pattern of the tire noise radiated from the automobile traffic.

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