Planning Data Services Section, Systems Usage Branch, Georgia Department of Transportation, and the results were tabulated in the final report (6). A total of 233 homes at the four sites (see Figure 2) were chosen to be surveyed. Of this total, 49 either were not at home or would not respond to the questions, which left a total response of 79 percent of the population of interest. The results of this survey are considered an accurate indication of the affected citizens' perception of the effectiveness of the noise barriers constructed for their community. A sample questionnaire is shown in Figure 3. The consensus of all four communities is presented in the following paragraphs.

The noise problem was perceived in a similar manner by residents who had lived in the area more than 10 years and those who had just moved in during the last few years. The average time of residence in the area was 6.6 years, which indicates that a number of people have willingly moved into an area that has high noise levels. Further analysis shows that 55 percent of the residents have lived there less than 10 years and 78 percent of these found noise to be a problem; 87 percent of those who lived there more than 10 years complained of a noise problem.

Nearly 50 percent of the respondents indicated that noise was a problem in conversation or sleep, 17 percent listed interference with work or study, and 33 percent said noise was a problem in outdoor activities. We also determined that 13.7 percent of the residents did not consider noise a problem.

Approximately 40 percent of the residents listed improved communication and sleeping conditions as a benefit of the noise wall. In addition, 44 percent found the environment more relaxing, and 37 percent said they used their yards more as a result of the noise wall. In describing the visual effects of the noise barriers, 65 percent of the respondents felt the barrier actually enhanced the appearance of the facility; only 10 percent felt they were detrimental.

An interesting item was that 32 percent of the residents thought that the reduced noise levels would benefit their community. However, almost 62 percent thought this would be a result of a smoother riding surface from the widening of I-285 and only 4 percent attributed the quieter environment to noise barriers.

By counting only those houses expected to experience noise levels in excess of 70 dB(A) (L10), we determined that the noise barriers cost $11 200/residence protected. More than 82 percent of the respondents thought this cost was justified and only 12 percent were not in favor of this expenditure.

## CONCLUSIONS

The data in Table 1 show that the STAMINA 1.0 model provides an accurate means of calculating highway traffic-generated noise. In every case except at site B, the difference in field measured and calculated noise levels was no more than 3 dB(A). Site B consisted of hilly terrain that broke the line of sight between source and receiver. The terrain was modeled to illustrate this shortcoming of the STAMINA 1.0 program. In fact, all cases in which a barrier was inserted yielded calculated noise levels higher than measured noise levels. This is apparently due to the loss of excess attenuation provided by surrounding trees and shrubs, since STAMINA 1.0 ignores this factor when the line of sight is broken. However, the STAMINA 1.0 model is still an accurate tool when used with this deficiency in mind. It provides the user with conservative estimates of the expected insertion loss.

Results of the survey indicate public support for a noise-abatement program. Also apparent is that efforts are needed to educate the public on what noise barriers are and how they are expected to work. This could be accomplished through meetings with affected communities after it has been determined that noise abatement is feasible for a given location.

A distinct difference in the perceived noise problem between residents adjacent to the Interstate and those beyond the second row of houses from the Interstate was found at sites A and B. Site C displayed virtually no difference over the entire sample area and site D exhibited only a slight decrease in the perceived noise problem with increased distance from the source. This inconsistency is believed to be a result of inexperience in constructing and administering the survey as well as lack of public awareness of what the noise barriers were and why they were erected.

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# Evaluation of Noise Barriers

RUDOLF W. HENDRIKS AND MAS HATANO

**This study was performed to evaluate Federal Highway Administration (FHWA) noise prediction and barrier design model 77-108, used by the California Department of Transportation. Barrier costs and community attitudes to barriers were also studied. Nine microphones were positioned at various heights and distances behind the barrier location before and after the barrier was constructed. One microphone was positioned 5 ft above the barrier to serve as a control. Sound levels were measured before and after the barrier was constructed at seven locations. Two sets of measurements were obtained at four**

**locations where the barrier was already constructed: one measurement behind and one measurement adjacent to the barrier. Traffic was counted simultaneously during the measurement periods. The data indicate that the FHWA model predicts about 3 dB(A) higher than field-measured sound levels. However, current practice is to make field measurements and adjust the model where barriers are constructed on existing freeways. The barrier design part of the model predicts about 1 dB(A) higher than field-measured levels after the prediction part of the model is adjusted. Questionnaires were used to collect information on community attitudes toward barriers. The data indicate that the residences that received the most insertion loss from barriers were the most satisfied. Although most residents were satisfied with the barriers, many adverse comments were received from individuals who were concerned about view, aesthetics, and cost. Cost per residence per dB(A) ranged from $626 to $2085. Variables such as length, height, location of barrier, and other work such as landscaping and irrigation systems affected the cost.**

Requirements for abating noise are covered in various state and federal laws. These are further detailed by regulations, policies, and practices developed by experience. Noise barriers are the primary means used by highway departments to mitigate noise.

Federal-Aid Highway Program Manual 7-7-3 (1) is the Federal Highway Administration (FHWA) document that covers the two major federal participating noise-abatement programs that the California Department of Transportation (Caltrans) is currently pursuing. These fall into type 1 (new or major reconstruction) and 2 (existing highway) categories and consist of constructing barriers in almost all cases. The procedure for designing barriers is covered in the FHWA Highway Traffic Noise Prediction Model (2).

Caltrans has constructed about 19 miles of noise barriers under the type 1 category program. No estimate is available for future barrier construction under this category; however, construction will probably continue to be significant.

Caltrans policy and procedure on freeway traffic noise reduction (no. P74-47, July 23, 1974) covers the retrofitting of noise barriers under the type 2 category projects. It was codified into law in 1979 and is in the California Streets and Highways Code Section 215.5. About 50 miles of barriers have been constructed to date under this category. More than 400 miles of barriers remain to be constructed under this program.

The need for a detailed study of current procedures for barrier design was recognized for several reasons. Limited feedback from the districts indicated good-to-poor correlation between design and actual field measurements. Design procedures specified by FHWA (2) are relatively new and were not officially adopted until January 1980 although they were published in December 1978. They had never been field validated in California. The most-important factor was the large inventory of barriers yet to be designed and constructed under the type 1 and 2 categories and the costs involved. Therefore, the primary objective of the study was to evaluate the FHWA procedure. Barriers that are underdesigned or overdesigned by an inaccurate procedure either provide inadequate protection or costs are unnecessarily high.

There were two secondary objectives:

1. To examine public reaction to noise barriers because of varied comments from residents who already had or were about to have barriers and
2. To evaluate costs for constructing barriers.

Because of a limited amount of suitable sites and barrier construction schedules that fall outside the study's time frame, only 11 barriers were selected (see table below). For the same reasons, barriers at sites 5, 8, 10, and 11 were existing barriers. Barrier and site geometries at the existing installations allowed satisfactory before-construction simulations by measuring noise levels on open areas adjacent to the barriers.

| Site | Name | District | Route | Post Mile | Location |
|---|---|---|---|---|---|
| 1 | Chapman | 4 | 17 | 15.8 | San Jose |
| 2 | Dana | 4 | 17 | 15.4 | San Jose |
| 3 | Fruitridge | 3 | 99 | 22.1 | Sacramento |
| 4 | Glenbrook | 3 | 50 | 5.3 | Sacramento |
| 5 | Meadowview | 3 | 5 | 16.2 | Sacramento |
| 6 | Alhambra | 7 | 10 | 23.6 | Los Angeles |
| 7 | St. Jerome | 7 | 405 | 24.4 | Los Angeles |
| 8 | Manteca | 10 | 99 | 7.9 | Manteca |
| 9 | Marlesta | 11 | 805 | 21.4 | San Diego |
| 10 | Parkway | 11 | 8 | 9.9 | San Diego |
| 11 | Guasti | 8 | 10 | 7.7 | Guasti |

The limited amount of suitable sites also narrowed the selection of available materials used in barriers. Only two basic materials could be studied: concrete walls (concrete block or precast concrete panels) and steel panels with concrete blocks. Community attitudes were not studied at each location because some barriers were already constructed, protected schools, or were surrounded by few residences. Cost evaluations were made for eight barriers. Costs for such things as landscaping and irrigation systems were not included.

## INSTRUMENTATION AND TYPICAL SETUP

All sound level meters (SLM) used in this study met the requirements for type 1 precision SLM per American National Standards Institute SI.4 (1971). The SLM were connected to a data logger designed for this study. The data logger has the capability of processing the output signals from 16 SLM simultaneously in descriptors of Peak, $L_{eq}$, $L_{10}$, and $L_{50}$. It also prints a histogram and various statistical values.

Instrument calibrations were performed by the Caltrans Transportation Laboratory and are traceable to the National Bureau of Standards. In addition, calibrations were performed in the field before and after the measurement period. Figure 1 shows typical instrument setups at the individual sites, microphone numbering, and site layout. In some instances the typical layout was not feasible because of space limitations, equipment availability, or breakdowns. Cross sections for each site are shown in Figures 2 and 3.

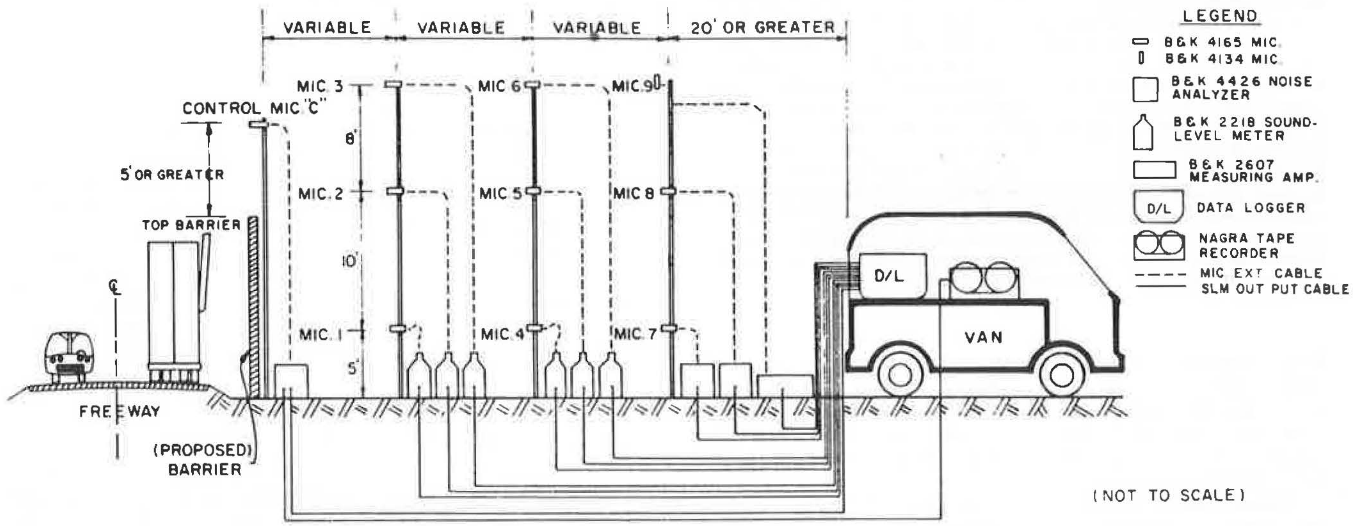
Sites 1, 2, and 6 had noise barriers on both sides of the highway. Calculations showed small [<1 dB(A)] noise contributions from reflections by the opposite barriers at these sites. A previous Caltrans study indicated that small changes due to reflected noise could be calculated but not measured in the field. No attempt was made, therefore, to measure the reflections from the opposite walls.

## MEASUREMENT RESULTS

Sound level data are not normally reported in 0.1 dB(A) increments because this implies an accuracy that is beyond the capability of the instrument. However, the data are shown in this report to 0.1 dB(A) as printed out by the recorders. The results of the before- and after-barrier $L_{eq}$ are summarized in Table 1.

The barrier field insertion losses (FIL) were calculated from before- and after-barrier measurements, by first normalizing before- and after-barrier data. In the normalization process, the difference between before- and after-noise levels of the control microphone were applied as a constant to

**Figure 1. Typical instrument setup for noise barrier evaluation.**




the noise levels of the remaining microphones of the same set.

At all measuring sites, noise levels were measured in terms of $L_{eq}$ dB(A). Measurement periods lasted a minimum of 20 min/run, with two or more runs taken before and after barrier construction. Simultaneous measurements with 10 or fewer microphone locations of varying heights and distances from the highway traffic source provided spatial resolution. Control microphones mounted at least 5 ft above the proposed or finished barrier were used to normalize before- and after-barrier traffic noise. The noise levels measured at these control microphones were assumed to be unaffected by the barrier due to their height. Differences between before- and after-noise levels at the control microphones were therefore assumed to be caused by differences in traffic volumes, mix, or distribution.

During the $L_{eq}$ measurements, traffic volumes were counted lane-by-lane and classified as automobiles, medium trucks, and heavy trucks. Traffic speeds were obtained by radar gun and by a car traveling with traffic. No measurements were made unless traffic was free flowing. Wind speeds were measured to ensure that no noise measurements were attempted during periods when wind speeds averaged more than 5 mph.

## Noise Levels Versus Heights and Distances

In general, the data indicate an average increase in before-barrier noise levels with an increase in microphone height and an average decrease with distance (Table 1 and Figure 4). However, the increases and decreases are not uniform due to different distances from the source, terrain features, and hard or soft site. The same trends are illustrated for the after-barrier average noise levels as for the before condition. As expected, heights and distances affected after-barrier noise levels more than for the before condition, depending on whether they were in the clear or shadow zone.

Average FIL (before and after) showed the expected trend of the greatest noise level decrease at the close tower (5-ft height) and the least decrease at the 23-ft height. The trends are less clear at towers 2 and 3. A detailed examination of the data at the individual sites indicates some reversal of the expected trends. These seemed to occur at the sites that were in cut. A few microphones in the clear zone even showed a slight increase in normalized noise levels after barrier construction (sites 4, 8, and 11).

A specific reason for each anomaly is not known but could be due to things such as berm effect (cut section) and dropoff rates as a function of barrier, ground cover, height, and distances. These factors affect FIL.

## Predicted Versus Measured Noise Levels

Predicted noise levels were determined by using the Caltrans computer program Sound 3, which is the same as the FHWA Stamina 1.0 program. Both programs are based on the FHWA noise prediction model (2). Table 2 shows the dropoff rate (hard and soft site) for each site and microphone height. The predicted noise levels before and after barrier construction are shown in Table 1.

### Before Barrier

A plot of predicted versus measured noise levels for all sites and microphones before barrier construction is shown in Figure 5. In general, the predicted noise level averages 3 dB(A) higher than the measured levels at around 70 dB(A). A skewed regression line indicates predicted levels 4 dB(A) and 2 dB(A) higher than measured levels at 65 and 75 dB(A).

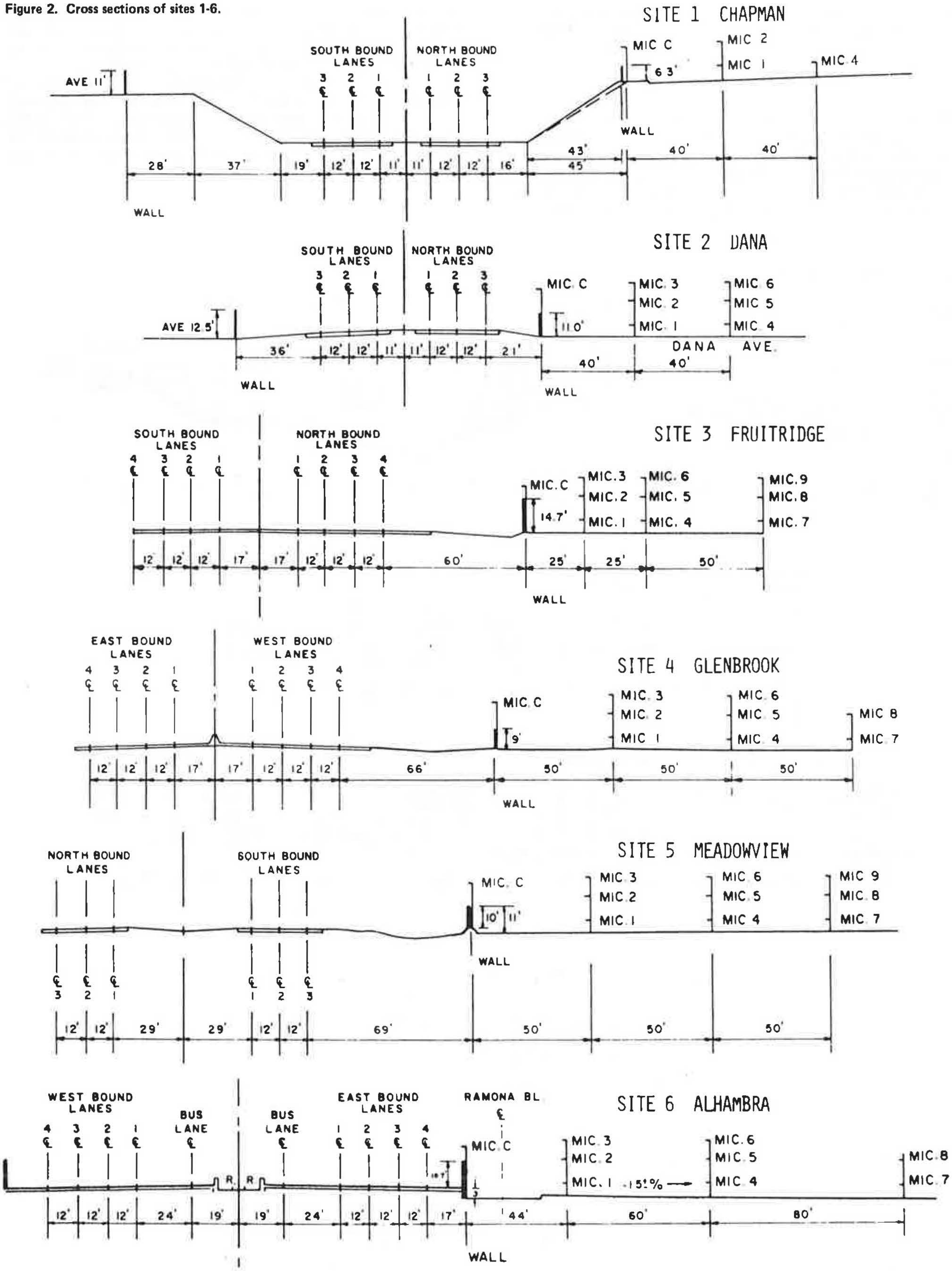
Figure 6 shows a plot of predicted versus measured noise levels for all sites at the low microphone location before barrier construction. This also shows an average 3 dB(A) higher predicted level and the regression line generally parallel to the balance line.

### After Barrier

A plot of predicted versus measured noise levels for all sites and microphones after barrier construction is shown in Figure 7. In general, the predicted noise levels average 4 dB(A) higher than measured levels at around 65 dB(A). A skewed regression line indicates predicted levels 6 dB(A) and 3 dB(A) higher than measured levels at 60 and 70 dB(A).

Figure 8 shows a plot of predicted versus measured levels for all sites at the low microphone location after barrier construction. The predicted noise levels average 5 dB(A) higher than measured

**Figure 2. Cross sections of sites 1-6.**



levels at 62 dB(A). A skewed regression line indicates predicted levels 7 dB(A) and 1 dB(A) higher than measured levels at 57 dB(A) and 67 dB(A).

FIL

A plot of normalized predicted versus measured FIL for all sites and microphones is shown in Figure 9. The skewed regression line for the data indicates that predicted levels average 4 dB(A) as compared with measured levels of 5 dB(A). These levels vary depending on the magnitude of the insertion loss. A similar plot for all sites and low microphones (Figure 10) shows the same general trends for all sites and all microphones [average predicted FIL of 5 dB(A) and average measured FIL of 6 dB(A)].

Figure 11 shows a frequency distribution of predicted minus measured noise levels (deviations) before and after barrier construction. The FHWA model overpredicted before-barrier noise levels by an average of 2.9 dB(A) and after-barrier noise levels by 3.8 dB(A).

Figure 3. Cross sections of sites 7-11.

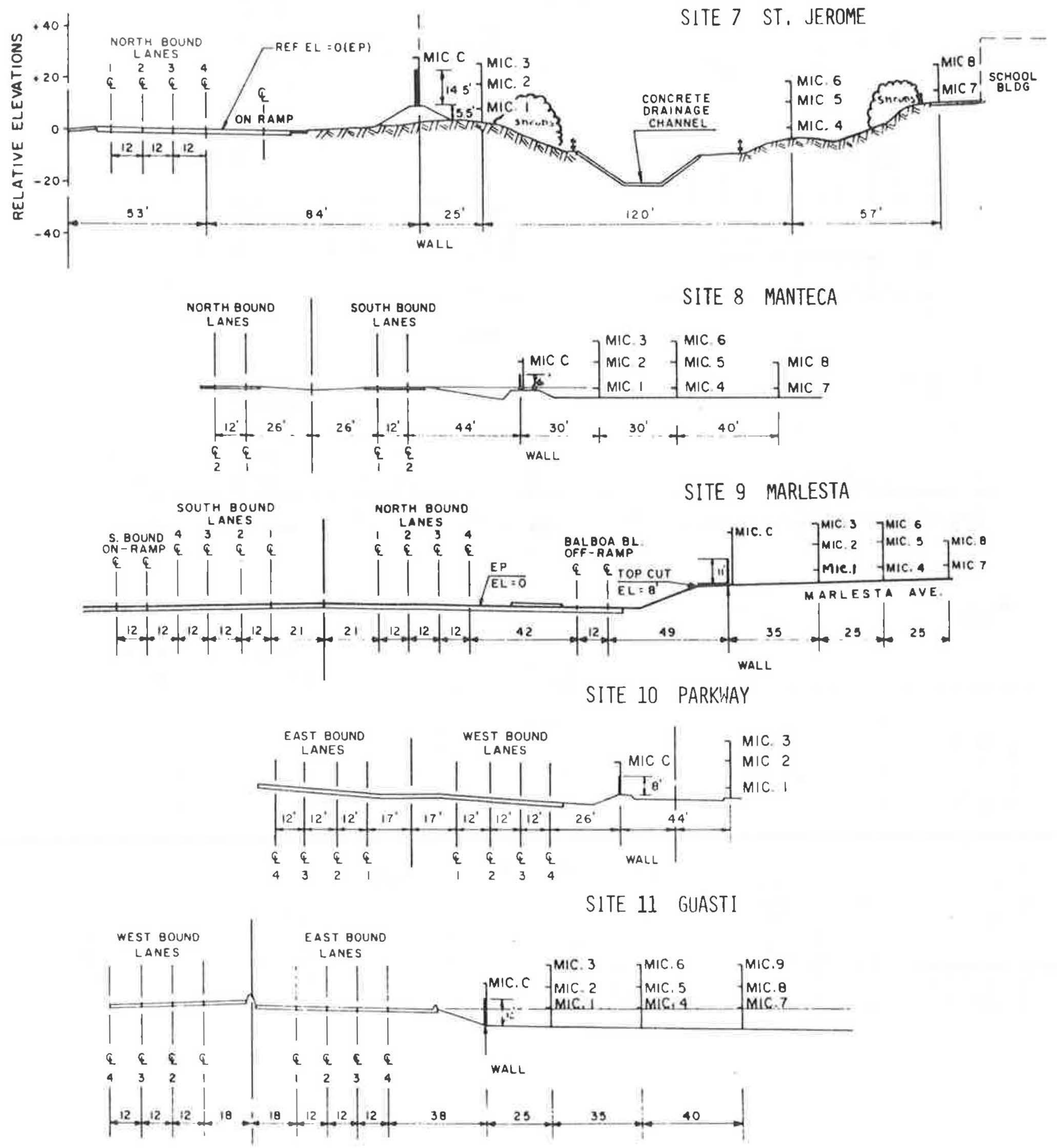


**Table 1. Summary of measured, predicted, and field insertion loss.**

| | | Sound Level [$L_{eq}$ dB(A)] | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Site 1 | | Site 2 | | Site 3 | | Site 4 | | Site 5[a] | | Site 6 | | Site 7 | | Site 8[a] | | Site 9 | | Site 10[a] | | Site 11[a] | | Site X | |
| Tower | Microphone | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| Control | Before | 78.4 | 78.4 | 80.4 | 81.5 | 77.1 | 78.9 | 78.8 | 77.8 | 75.3 | 76.0 | 83.0 | 83.8 | 78.9 | 80.0 | 75.2 | 77.7 | 75.9 | 74.8 | 80.4 | 79.6 | 78.9 | 79.8 | 78.4 | 79.0 |
| | After | 78.8 | 78.0 | 81.1 | 81.0 | 77.1 | 78.7 | 77.0 | 77.2 | 74.0 | 75.7 | 80.9 | 80.5 | 77.9 | 80.2 | 75.5 | 78.2 | 75.9 | 74.8 | 80.0 | 79.8 | 78.7 | 79.4 | 77.9 | 78.5 |
| 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | 64.9 | 68.2 | 72.7 | 78.8 | 72.4 | 75.1 | 71.1 | 72.5 | 68.4 | 70.7 | 75.5 | 79.7 | 73.5 | 76.0 | 69.4 | 73.5 | 68.6 | 68.8 | 74.6 | 74.5 | 71.4 | 75.1 | 71.1 | 73.9 |
| | After | 62.5 | 65.5 | 66.4 | 70.0 | 61.2 | 64.3 | 62.5 | 68.2 | 56.7 | 65.6 | 64.3 | 67.1 | 61.1 | 62.5 | 61.8 | 69.7 | 62.9 | 63.1 | 66.6 | 68.7 | 64.0 | 70.8 | 62.7 | 66.9 |
| | Field insertion loss | 2.8 | 2.3 | 7.0 | 8.3 | 11.2 | 10.6 | 6.8 | 3.7 | 10.4 | 4.8 | 9.1 | 9.3 | 11.4 | 13.7 | 7.9 | 4.3 | 5.7 | 5.7 | 7.6 | 6.0 | 7.2 | 3.9 | 7.9 | 6.7 |
| | 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | 68.2 | 75.6 | 75.1 | 78.8 | 75.4 | 77.8 | 76.0 | 75.7 | 71.3 | 73.9 | 78.3 | 80.5 | 76.7 | 79.1 | 72.1 | 75.9 | 73.3 | 73.3 | 76.9 | 76.7 | 73.9 | 77.7 | 74.3 | 76.8 |
| | After | 66.5 | 70.4 | 69.0 | 73.1 | 68.4 | 71.7 | 70.3 | 73.3 | 62.1 | 69.4 | 67.8 | 71.5 | 64.1 | 68.2 | 68.6 | 75.8 | 69.3 | 69.0 | 71.5 | 73.5 | 69.3 | 76.6 | 67.9 | 72.1 |
| | Field insertion loss | 2.1 | 4.8 | 6.8 | 5.2 | 7.0 | 5.9 | 3.9 | 1.8 | 7.9 | 4.2 | 8.4 | 5.7 | 11.6 | 11.1 | 3.8 | 0.6 | 4.0 | 4.3 | 5.0 | 3.4 | 4.4 | 0.7 | 5.9 | 4.2 |
| | 3 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | | | 75.8 | 78.7 | 76.7 | 77.8 | 75.7 | 75.8 | 72.6 | 73.8 | 78.5 | 80.4 | 76.7 | 79.1 | 73.2 | 75.8 | 74.3 | 73.5 | 77.4 | 76.7 | 75.7 | 77.9 | 75.7 | 77.0 |
| | After | | | 73.9 | 76.6 | 74.9 | 77.2 | 75.8 | 75.2 | 68.8 | 73.5 | 72.7 | 74.7 | 72.1 | 74.0 | 73.7 | 76.4 | 74.0 | 73.3 | 74.6 | 75.7 | 76.1 | 77.5 | 73.7 | 75.4 |
| | Field insertion loss | | | 2.6 | 1.6 | 1.8 | 0.2 | -1.9 | 0 | 2.5 | 0 | 3.7 | 2.4 | 3.6 | 5.3 | -0.2 | -0.1 | 0.3 | 0.2 | 2.4 | 1.2 | -0.6 | 0 | 1.5 | 1.1 |
| | 4 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | 63.3 | 64.8 | 71.2 | 76.3 | 71.7 | 73.7 | 69.3 | 70.2 | 65.2 | 68.6 | 69.4 | 76.1 | 63.7 | 68.6 | 68.6 | 71.6 | 67.2 | 66.9 | | | 69.3 | 72.3 | 67.9 | 70.9 |
| | After | 60.1 | 62.5 | 64.1 | 68.7 | 62.8 | 65.1 | 61.7 | 67.2 | 55.7 | 65.8 | 61.5 | 65.6 | 61.0 | 65.2 | 61.4 | 69.7 | 62.5 | 63.3 | | | 63.0 | 70.0 | 61.4 | 66.3 |
| | Field insertion loss | 3.6 | 1.9 | 7.8 | 7.1 | 8.9 | 8.4 | 5.8 | 2.4 | 8.2 | 2.5 | 5.8 | 7.2 | 1.7 | 3.6 | 7.5 | 2.4 | 4.7 | 3.6 | | | 6.1 | 1.9 | 6.0 | 4.1 |
| 2 | 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | | | 72.0 | 76.3 | 74.4 | 76.9 | 72.1 | 74.1 | 69.5 | 72.3 | 71.0 | 77.2 | 67.8 | 72.3 | 70.9 | 74.6 | 73.1 | 72.3 | | | 71.0 | 75.6 | 71.3 | 74.7 |
| | After | | | 66.0 | 70.7 | 66.7 | 70.3 | 66.1 | 69.7 | 59.3 | 67.7 | 64.4 | 68.6 | 62.9 | 66.2 | 64.8 | 74.6 | 67.2 | 68.2 | | | 66.5 | 73.2 | 64.9 | 69.9 |
| | Field insertion loss | | | 6.7 | 5.1 | 7.7 | 6.5 | 4.2 | 3.8 | 8.9 | 4.3 | 4.5 | 5.3 | 3.9 | 6.3 | 6.4 | 0.5 | 5.9 | 4.1 | | | 4.3 | 2.0 | 5.9 | 4.3 |
| | 6 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | | | 72.1 | 76.4 | 74.4 | 76.9 | 73.2 | 74.4 | 70.7 | 72.3 | 74.9 | 77.6 | 69.8 | 75.1 | 71.6 | 74.6 | 73.4 | 72.7 | | | 72.8 | 75.8 | 72.5 | 75.1 |
| | After | | | 68.6 | 72.5 | 71.5 | 73.9 | 69.5 | 73.0 | 62.9 | 70.9 | 67.5 | 70.6 | 63.6 | 67.4 | 69.1 | 75.0 | 72.1 | 71.7 | | | 70.7 | 75.0 | 68.4 | 72.2 |
| | Field insertion loss | | | 4.2 | 3.4 | 2.9 | 2.7 | 1.9 | 0.8 | 6.5 | 1.1 | 5.3 | 3.7 | 5.2 | 7.9 | 2.8 | 0.1 | 1.3 | 1.0 | | | 1.9 | 0.4 | 3.6 | 2.4 |
| 3 | 7 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | | | | | 67.9 | 71.7 | 63.9 | 68.4 | 62.1 | 66.9 | 65.2 | 72.7 | 67.0 | 71.6 | 67.8 | 69.8 | 65.0 | 65.7 | | | 67.3 | 70.0 | 65.8 | 69.5 |
| | After | | | | | 62.5 | 65.1 | 60.0 | 66.3 | 55.0 | 65.6 | 59.2 | 63.9 | 61.8 | 66.0 | 62.3 | 68.9 | 61.4 | 63.1 | | | 62.0 | 69.0 | 60.5 | 65.6 |
| | Field insertion loss | | | | | 5.4 | 6.4 | 2.1 | 1.5 | 5.8 | 1.0 | 3.9 | 5.5 | 4.2 | 7.8 | 5.8 | 1.4 | 3.6 | 2.6 | | | 5.1 | 0.6 | 4.8 | 3.4 |
| | 8 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | | | | | 71.2 | 75.5 | 69.5 | 72.7 | 67.4 | 71.0 | 67.3 | 73.9 | 70.0 | 73.9 | 68.5 | 73.3 | 71.4 | 71.0 | | | 68.4 | 73.9 | 69.2 | 73.2 |
| | After | | | | | 65.3 | 68.5 | 64.2 | 68.6 | 57.8 | 66.8 | 61.5 | 66.4 | 63.6 | 66.5 | 62.9 | 72.7 | 66.2 | 67.5 | | | 64.4 | 71.5 | 63.2 | 68.6 |
| | Field insertion loss | | | | | 5.9 | 6.8 | 3.5 | 3.5 | 8.3 | 3.9 | 3.7 | 4.2 | 5.4 | 7.6 | 5.9 | 1.1 | 5.2 | 3.5 | | | 3.8 | 2.0 | 5.5 | 4.1 |
| | 9 | | | | | | | | | | | | | | | | | | | | | | | | |
| | Before | | | | | 72.3 | 75.5 | | | 68.5 | 71.0 | | | | | | | | | | | 69.9 | 74.0 | 70.2 | 73.5 |
| | After | | | | | 67.2 | 70.3 | | | 60.3 | 68.5 | | | | | | | | | | | 67.2 | 73.5 | 64.9 | 70.8 |
| | Field insertion loss | | | | | 5.1 | 4.9 | | | 6.9 | 2.2 | | | | | | | | | | | 2.5 | 0.5 | 4.8 | 2.2 |

[a]Barriers already in place; before levels are simulated.

Summary and Comments

A detailed examination of the data from each site indicates that noise levels for the various conditions were affected by dropoff rates due to hard and soft sites, effect of barriers on soft sites, heights of microphones, and cut section (berm effect). As an example, depending on the magnitude of the ground effect and barrier attenuation, some high receivers far from the barrier may benefit from a greater FIL than will lower receivers at the same distance (Table 1). Other barriers showed a FIL

Figure 4. Average measured noise levels for various microphone heights and distances.

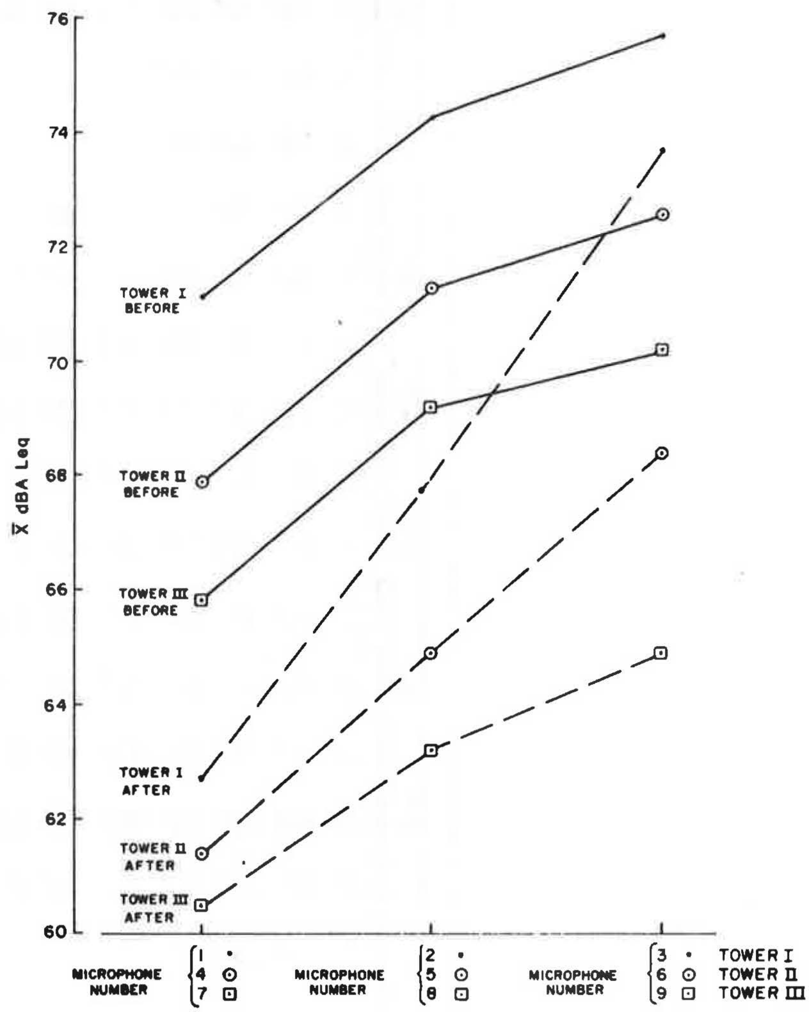



Table 2. Dropoff rates as distance is doubled.

| Site | Dropoff Rate [dB(A)] | | | | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Before | | | | After | | | | |
| | Control | Low | Middle | High | Control | Low | Middle | High | |
| 1. Chapman | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | Soft site cut section |
| 2. Dana | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | Hard site |
| 3. Fruitridge | 3 | 4.5 | 3 | 3 | 3 | 3 | 3 | 3 | Soft site |
| 4. Glenbrook | 3 | 4.5 | 3 | 3 | 3 | 3 | 3 | 3 | Soft site wall <10 ft |
| 5. Meadowview | 3 | 4.5 | 3 | 3 | 3 | 3 | 3 | 3 | Soft site wall <10 ft |
| 6. Alhambra | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | Hard site |
| 7. St. Jerome | 3 | 3[a] | 3 | 3 | 3 | 3 | 3 | 3 | Soft site before berm |
| 8. Manteca | 3 | 4.5 | 3 | 3 | 3 | 3 | 3 | 3 | Soft site wall < 10 ft |
| 9. Marlesta | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | Soft site before berm |
| 10. Parkway | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | Hard site |
| 11. Guasti | 3 | 4.5 | 3 | 3 | 3 | 3 | 3 | 3 | Soft site wall <10 ft |

Note: SOUND 3 is Caltrans' version of STAMINA 1.0 computer program. All present computer programs default to a dropoff rate of 3 dB(A)/DD when barrier attenuation is encountered. This is different from FHWA Manual 77-108 (2), which recommends retaining soft-site dropoff rates (or alpha factors) for barriers less than 10 ft high.

[a]Used 4.5 dB(A) for microphone 1 at St. Jerome's before (did not receive attenuation from before berm).

Figure 5. Predicted versus measured dB(A) for all sites, all microphones, $L_{eq}$, before.

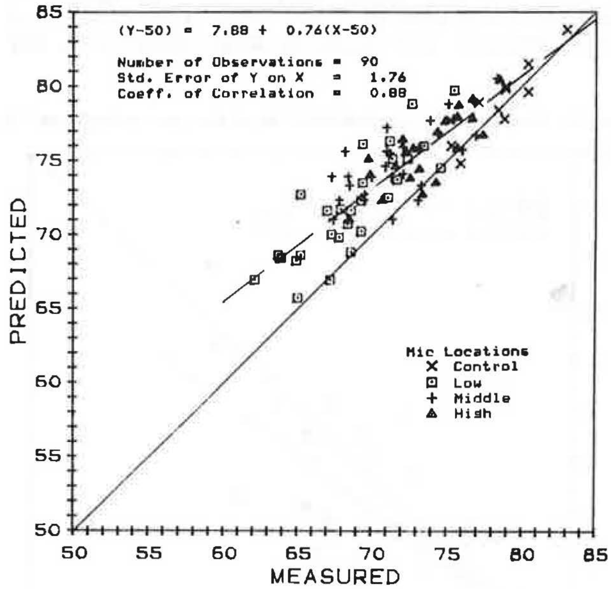



Figure 6. Predicted versus measured dB(A) for all sites, low microphones, $L_{eq}$, before.

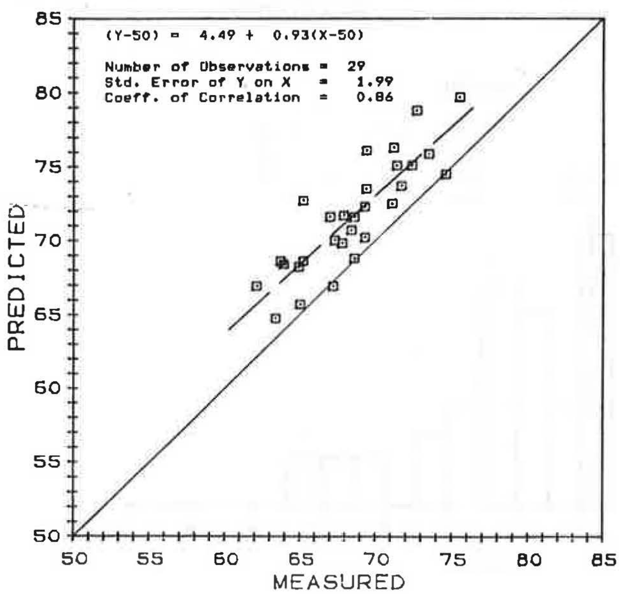



Figure 7. Predicted versus measured dB(A) for all sites, low microphones $L_{eq}$, after.

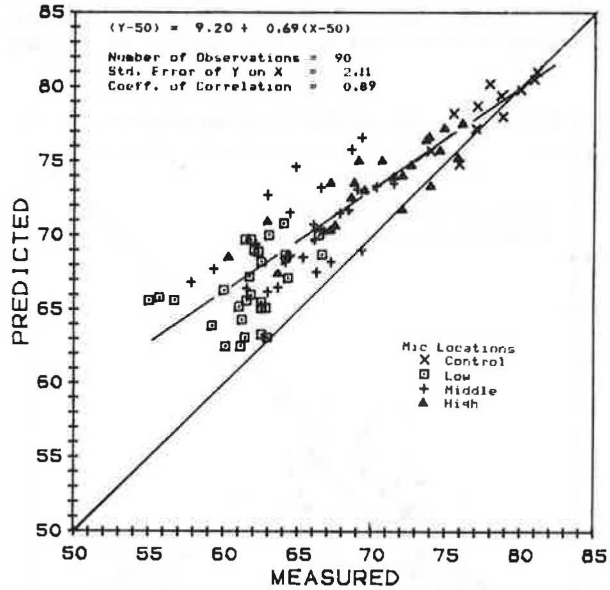
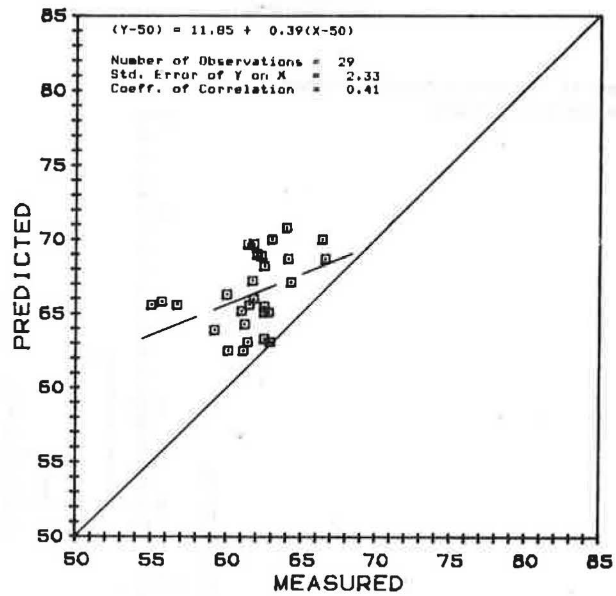



Figure 8. Predicted versus measured dB(A) for all sites, low microphones, $L_{eq}$, after.




less than 3 dB(A), which is not effective from either a cost or acoustic standpoint.

The tendency is for all calculated regression lines between measured and predicted noise levels to be skewed with the least difference at the higher levels. An estimated regression line parallel to the 45° line may be more illustrative of the difference between measured and predicted levels. However, all the data indicate that the predicted levels are higher than measured levels, regardless of how the regression line is drawn.

## COMMUNITY ATTITUDES

Community acceptance of barriers was also evaluated. Some dissatisfactions were expressed by residents before and after a barrier had been built. The extent of this problem was to be defined. Three major issues were to be evaluated:

1. Barrier acceptance,
2. Change in attitude toward the barrier before and after construction, and
3. Perceived versus measured noise response.

Evaluation of community acceptance of barriers was accomplished by using a questionnaire mailed to residents in the first three and four rows of houses behind the wall. The questionnaire was mailed before and after construction of the barrier. The weaknesses of mailed questionnaires were recognized, but they were considered the most cost-effective way to gather this information.

At several locations in the community behind the barriers, noise measurements were taken 5 ft above the ground in terms of 20 min $L_{eq}$ dB(A) to characterize ambient noise levels before and after the barrier. These were averaged with the barrier performance measurements and were useful in placing the first three or four rows of residences near each site in the following noise reduction categories: <3, 3-5, and 6-9 dB(A) (Table 3). Responses to questions concerning perceived noise reduction could then be compared with measured noise reductions. For

Figure 9. Predicted versus measured dB(A) for all sites, all microphones, FIL.

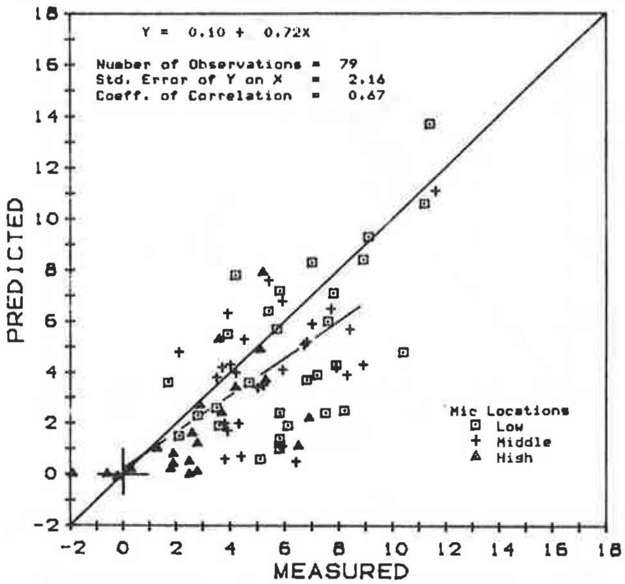



Figure 10. Predicted versus measured dB(A) for all sites, low microphones, FIL.

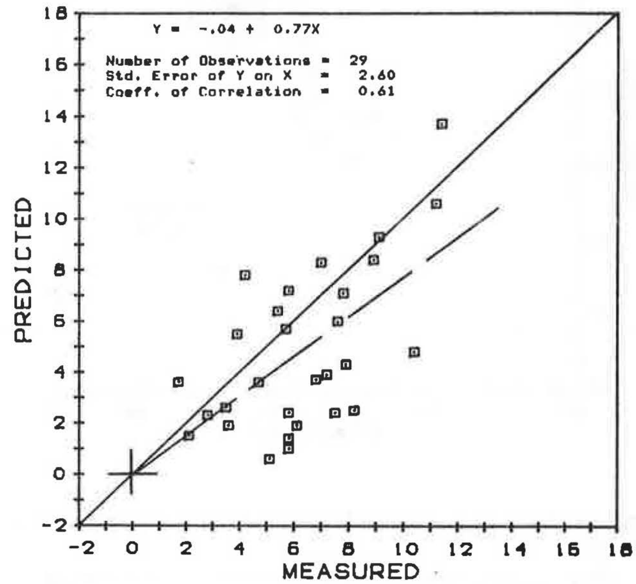



Figure 11. Frequency distribution of FHWA model deviation before and after.

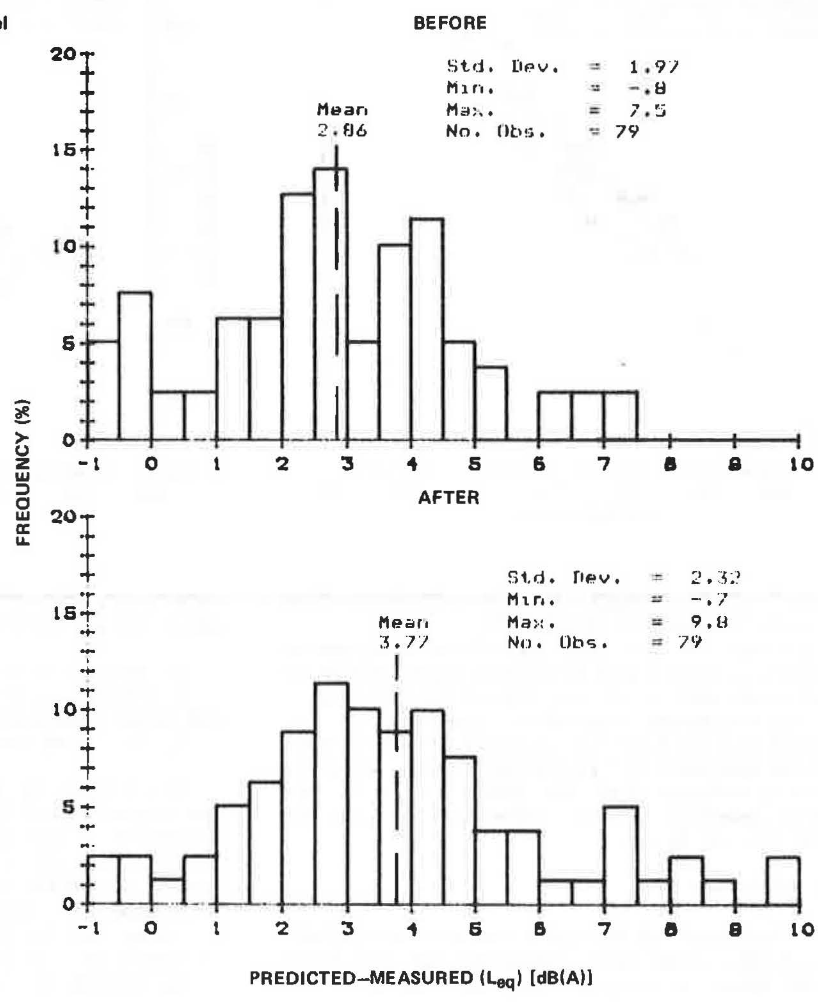


**Table 3. Average noise reduction.**

| Site | Row | Measured Noise Reduction [dB(A)] | Site | Row | Measured Noise Reduction [dB(A)] |
|---|---|---|---|---|---|
| 1 | 1 | <3 | 3 | 2 | 3-5 |
| | 2 | <3 | | 3 | <3 |
| | 3 | <3 | | 4 | <3 |
| 2 | 1 | 6-9 | 6 | 1 | 6-9 |
| | 2 | 3-5 | | 2 | 6-9 |
| | 3 | <3 | | 3 | 3-5 |
| 3 | 1 | 6-9 | | 4 | <3 |

**Table 4. Community response to questionnaire.**

| | Questionnaire Response (%) | | | | Total | |
|---|---|---|---|---|---|---|
| Site | Row 1 | Row 2 | Row 3 | Row 4 | No. | Percent |
| 1 and 2 | | | | | 438 | |
| Before | 61 | 55 | 58 | | 256 | 58 |
| After | 80 | 56 | 65 | | 299 | 68 |
| 3 | | | | | 46 | |
| Before | 50 | 50 | 44 | 41 | 21 | 46 |
| After | 53 | 33 | 70 | 56 | 23 | 53 |
| 6 | | | | | 110 | |
| Before | 39 | 14 | 24 | 40 | 35 | 32 |
| After | 41 | 41 | 35 | 27 | 42 | 38 |

**Table 5. Significance of difference between numbers of before and after responses.**

| Survey Area | Barrier Stage | No. Responded | No. Not Responded | Calculated Chi²[a] | Chi²[b] | Reject | Significant |
|---|---|---|---|---|---|---|---|
| Row | | | | | | | |
| 1 | Before | 144 | 116 | 10.83 | 3.841 | Yes | Yes |
| | After | 180 | 78 | | | | |
| 2 | Before | 91 | 93 | 7.97 | 3.841 | Yes | Yes |
| | After | 117 | 64 | | | | |
| 3 and 4 | Before | 77 | 73 | 0.98 | 3.841 | No | No |
| | After | 86 | 63 | | | | |
| Site | | | | | | | |
| 1 and 2 | Before | 256 | 182 | 8.67 | 3.841 | Yes | Yes |
| | After | 299 | 139 | | | | |
| 3 | Before | 21 | 25 | 0.28 | 3.841 | No | No |
| | After | 23 | 20 | | | | |
| 6 | Before | 35 | 75 | 0.72 | 3.841 | No | No |
| | After | 42 | 68 | | | | |

[a]df = 1. [b]df = 0.05.

**Table 6. Acceptance of barrier appearance.**

| | Response by Row (%) | | | |
|---|---|---|---|---|
| Question | 1 (n = 180) | 2 (n = 98) | 3 and 4 (n = 87) | Total (n = 365) |
| Barrier appearance | | | | |
| Very acceptable | 51 | 46 | 56 | 51 |
| OK | 37 | 43 | 33 | 38 |
| No | 12 | 11 | 11 | 11 |
| Overall barrier acceptance | | | | |
| Like | 73 | 64 | 65 | 69 |
| Dislike | 9 | 9 | 11 | 9 |
| Neutral | 18 | 27 | 24 | 22 |

**Table 7. Overall barrier acceptance.**

| | Response by Site (%) | | | |
|---|---|---|---|---|
| Question | 1 and 2 (n = 306) | 3 (n = 23) | 6 (n = 42) | Total (n = 371) |
| Barrier appearance | | | | |
| Very acceptable | 50 | 65 | 52 | 51 |
| OK | 38 | 26 | 43 | 38 |
| No | 12 | 9 | 5 | 11 |
| Overall barrier acceptance | | | | |
| Like | 67 | 83 | 75 | 69 |
| Dislike | 10 | 4 | 10 | 10 |
| Neutral | 23 | 13 | 15 | 21 |

**Table 8. Attitude change—advantage versus disadvantage.**

| | Advantages Outweigh Disadvantages | | | | | |
|---|---|---|---|---|---|---|
| | Yes (%) | | No (%) | | No. of Respondents | |
| Survey Area | Before | After | Before | After | Before | After |
| Row | | | | | | |
| 1 | 85 | 84 | 15 | 16 | 125 | 172 |
| 2 | 82 | 79 | 18 | 21 | 60 | 94 |
| 3 and 4 | 86 | 72 | 14 | 28 | 59 | 75 |
| Site | | | | | | |
| 1 and 2 | 85 | 80 | 15 | 20 | 194 | 279 |
| 3 | 89 | 77 | 11 | 23 | 18 | 22 |
| 6 | 78 | 85 | 22 | 15 | 32 | 40 |

this purpose the San Jose barrier location was separated into barriers represented by site 1 (Chapman) and site 2 (Dana).

## Responses

Table 4 summarizes the number and percentage of questionnaires mailed and returned, before and after construction of the barrier.

Chi-square tests were performed to detect any significant differences between two variables. A chi-square test determines the probability that any difference between observed sample data and expected data could have occurred by chance. It can be implied that there is a significant difference between the two variables if the chi-square value exceeds a certain critical value at a selected confidence level. A 95 percent confidence level ($\chi^2 = 0.05$) was used for this report.

The chi-square test on before versus after responses indicated that, within row 1 and row 2 (all sites combined), responses increased significantly after the barriers were constructed. There was no significant difference in rows 3 and 4. The calculated chi-squares were highest in row 1 and lowest in rows 3 and 4. This demonstrated that interest in responding to the questionnaire declined as the distance from residences to barrier increased.

An analysis of all rows combined by site indi-

Table 9. Overall attitude change.

| Survey Area | Like (%) Before | Like (%) After | Dislike (%) Before | Dislike (%) After | Neutral (%) Before | Neutral (%) After | No. of Respondents Before | No. of Respondents After |
|---|---|---|---|---|---|---|---|---|
| Row | | | | | | | | |
| 1 | 79 | 73 | 5 | 9 | 16 | 18 | 136 | 180 |
| 2 | 72 | 64 | 8 | 9 | 20 | 27 | 89 | 97 |
| 3 and 4 | 61 | 65 | 8 | 11 | 31 | 24 | 77 | 86 |
| Site | | | | | | | | |
| 1 and 2 | 71 | 67 | 8 | 10 | 21 | 23 | 249 | 299 |
| 3 | 79 | 83 | 0 | 4 | 21 | 13 | 19 | 23 |
| 6 | 82 | 75 | 3 | 10 | 15 | 15 | 34 | 41 |

Table 10. Cost-effectiveness of Caltrans barriers.

| Barrier Sites | Length (ft) | First Row Frontage Units | FIL [$L_{eq}$ dB(A)] | Cost ($) Total (000s) | Explicit (000s) | Per Linear Foot | Per dB(A)[a] | Per FRU.dB(A)[a] |
|---|---|---|---|---|---|---|---|---|
| 1 and 2 | 11 456 | 190 | 6 | 2063 | 1120 | 180 | | 982 |
| 3 | 2 650 | 17 | 9 | 477 | 319 | 180 | | 2085 |
| 6 | 17 318 | 207 | 9 | 2840 | 1167 | 164 | | 626 |
| 7 | 1 280 | School | 5 | 291 | 258 | 227 | 51 600 | |
| 9 | 870 | 15 | 5 | 134 | 102 | 154 | | 1360 |
| 10 | 768 | 4 | 8 | 78 | 60 | 102 | | 1875 |
| 11 | 385 | School | 7 | 57 | 45 | 148 | 6 428 | |

[a]Explicit cost only.

cated a significant increase in after-barrier responses (sites 1 and 2) and no significant difference at sites 3 and 6. The results of the latter two sites may have been caused by insufficient data. Table 5 summarizes the calculated and critical chi-squares, degrees of freedom, and significance used to arrive at the above conclusions.

## Analysis and Discussions

The results of the questionnaires were also tested statistically for significance by using the chi-square test with 95 percent confidence level. However, the results may not represent the views of all the residents who live in the first three or four rows behind the barriers. The results represent only the views of the residents who responded. Evaluation was performed by combining all sites by row and all rows by site. The data are shown on tables for various cases and conclusions are drawn on the basis of the chi-square analysis.

## Barrier Acceptance

Table 6 shows data about the appearance of the barrier and its overall acceptance by row. Table 7 gives the same data by site. An overwhelming number of respondents by row (89 percent) and site (91 percent) thought that the barrier appearance was OK or very acceptable (combined). The percentages of acceptance by row (67 percent) and site (75 percent) were also high. Neither table showed significant differences in response between rows or between sites.

The table below gives data relating to barrier acceptance versus measured noise reduction. The data indicate a significant difference in response among residents in the three categories. The respondents' overall feeling toward the barrier was governed by the amount of noise reduction.

| Measured Noise Reduction [dB(A)] | Response (%) Like | Dislike | Neutral |
|---|---|---|---|
| 6-9 (n = 178) | 75 | 7 | 18 |
| 3-5 (n = 84) | 68 | 6 | 26 |
| <3 (n = 101) | 58 | 16 | 26 |

The table below gives data that relate barrier acceptance and neighborhood improvement. Residents were asked, "Has the barrier met your expectations in improving your neighborhood?"

| Survey Area | Response (%) Yes | No | Undecided |
|---|---|---|---|
| Row | | | |
| 1 (n = 182) | 58 | 26 | 16 |
| 2 (n = 86) | 58 | 27 | 15 |
| 3 and 4 (n = 86) | 64 | 15 | 21 |
| Total (n = 354) | 60 | 23 | 17 |
| Site | | | |
| 1 and 2 (n = 289) | 56 | 26 | 18 |
| 3 (n = 23) | 83 | 13 | 4 |
| 6 (n = 42) | 74 | 12 | 14 |
| Total (n = 354) | 60 | 23 | 17 |

The responses showed no significant difference among rows, although a higher percentage of respondents in rows 3 and 4 thought that the barrier improved the neighborhood. Responses by sites showed a significant difference; those at sites 3 and 6 showed the highest favorable response.

## Attitude Change

Table 8 shows the response to the question, "Do the advantages of the barrier outweigh the disadvantages?" Both the before and after respondents by row and site overwhelmingly considered the barriers to be an advantage. However, note that, in every case, the number of respondents after the barrier was greater than the number before the barrier was constructed.

Table 9 shows the response to the question, "How do you feel about the barrier overall?" The percentages were generally lower than for Table 8 but showed the same favorable opinion of barriers before and after construction. Again, the number of respondents after barrier construction increased.

## Measured Versus Perceived Noise Reduction

The table below gives data related to measured versus perceived noise levels before and after barrier construction. The respondents indicated a substantial quieting of the neighborhood in the 6-9 and 3-5 dB(A) categories. There was also a 14 percent increase in the <3 dB(A) category, but it was not statistically significant.

| Measured Noise Reduction [dB(A)] | Opinion of Neighborhood Noise (%): Little Noisy to Very Quiet | Noisy to Very Noisy | No. of Respondents |
|---|---|---|---|
| 6-9 | | | |
| Before | 27 | 73 | 126 |
| After | 73 | 27 | 185 |
| 3-5 | | | |
| Before | 59 | 41 | 69 |
| After | 77 | 23 | 71 |
| <3 | | | |
| Before | 65 | 35 | 84 |
| After | 79 | 21 | 103 |

A significant difference can be seen in the before and after responses in the 6-9 dB(A) and 3-5 dB(A) but not in the <3 dB(A) categories. There is a significant difference in the before and after change in responses among the three categories.

## BARRIER COST-EFFECTIVENESS

The emphasis on reducing highway construction costs on state and federal levels has always been a consideration but has increased steadily under pressure of inflation and reduced revenues. The greatest challenge in noise barrier design lies in providing acoustically and aesthetically adequate noise barriers for the least cost. Before the cost-effectiveness of the Caltrans barriers could be analyzed, we needed to define the effectiveness of each barrier and the associated barrier costs.

Barrier effectiveness was defined by the amount of FIL in $L_{eq}$, dB(A), at the sites in this study. The FILs measured by the low microphone located at representative distances to the first row of houses were multiplied by the number of first-row residences to get an indication of barrier effectiveness.

A special problem occurred when the first row behind the barrier included apartments or commercial property. In this case, the frontage length of the property was equated to the number of frontage lengths of adjacent single-family homes. Thus, the affected property was assigned an equivalent number of frontage units. (One single-family residence is one frontage unit or FRU.) The unit for effectiveness was therefore FRU dB(A); [i.e., a barrier that protects 20 first row FRUs that has a FIL of 10 dB(A) would have an effectiveness of 200 FRU dB(A)].

This method of defining barrier effectiveness implies that the only benefits from barriers are acoustical benefits and the first-row residences are the only recipients of the barriers' benefits. In reality, the barrier benefits are more complex. The findings on community acceptance clearly indicate that benefits of barriers should not only be measured by acoustical effects but also by nonacoustical effects such as aesthetics, physical and visual separation from freeway, safety, and air pollution. Some of these nonacoustical effects may enhance the acoustical benefits; others may partly or entirely offset them. Ideally, the net total of acoustical and nonacoustical benefits should be studied in a cost-effectiveness analysis. Unfortunately, the nonacoustical effects are mainly subjective perceptions and cannot be readily quantified. For this reason, only acoustical benefits were considered.

Assigning all benefits to the first row was another simplification. Although the greatest impact of the barrier is perceived at the first row, the second and possibly third row also enjoy some FIL. There is, however, a greater variation of impacts in these rows, depending on the amount of shielding by first row residences. An assessment of the noise attenuation value for rows two or three would be difficult. Therefore, all benefits were assessed at row one, which results in a lower benefit than actually achieved.

The term explicit cost was used to determine the acoustical cost-effectiveness for first-row frontage units. Explicit cost is only for barrier cost and does not include items such as landscaping and irrigation systems.

Table 10 presents the results of the analysis. Barrier sites 7 and 11 were school noise projects. For these, only the explicit cost per dB(A) noise reduction in terms of $L_{eq}$ were determined. The remaining barriers were compared in terms of cost per FRU dB(A) [explicit cost divided by number of FRU dB(A)]. Also presented are the total costs per linear foot. The Caltrans barriers evaluated in this report ranged from $626 to $2085/residence dB(A).

The large variations in costs and cost-effectiveness were due to the site geometry, barrier length and location, and community layout. Barriers that protect few homes are obviously less cost effective (i.e., sites 3, 9, and 10). Long barriers that protect many homes are more cost effective (i.e., sites 1, 2, and 6).

Caltrans District 7 in Los Angeles reported the cost-effectiveness of 12 barrier projects in terms of cost per residence dB(A) and cost per person dB(A) based on 2.6 persons/residence. The cost per residence dB(A) ranged from $675 to $2290 and showed general agreement with the results from this study. According to the District 7 study, a major factor that affects the cost of noise barriers is the location. In general, noise barriers located on the freeway shoulder were more expensive than those on the right-of-way line. The cost differential (approximately $40/linear foot) was due to additional requirements for barriers constructed at the edge of shoulder, including concrete safety barriers; maintenance access gates or overlapping openings; and revisions to existing signs, light standards, guardrails, utilities, landscaping irrigation, and traffic control.

Other major factors concerning the costs of barriers in general are accessibility to the work site, irregular terrain, and, of course, the height of the barrier.

## CONCLUSIONS

The FHWA procedure (2) for predicting noise levels is satisfactory when traffic noise levels can be validated in the field. These conditions occur when field noise measurements can be made on traffic that currently uses the facility. Adjustments are made to the model in these cases. All type 1 and many type 2 projects fall under this category. This procedure predicted noise levels about 3 dB(A) higher than field-measured levels for a before-barrier condition at a microphone height of 5 ft and noise level around 70 dB(A). It is slightly higher and lower than 3 dB(A) at noise levels below and above 70 dB(A). Similar trends were noted for microphone heights of 15 and 23 ft. No adjustments to the model can be made on new alignments because no traffic noise can be measured. This can result in over-design of barrier height by around 5 ft.

The FHWA procedure predicted noise levels about 4 dB(A) higher than field-measured levels for an after-barrier condition at a microphone height of 5 ft and noise levels around 61 dB(A). Other variables showed similar trends as for the before-barrier conclusion. The net result is about 1 dB(A) more insertion loss after barrier construction if the model can be field-validated before barrier construction.

Responses to questionnaires indicated general satisfaction with barriers. Residents in the second and third row of houses next to the freeways were generally not affected by traffic noise. Some individuals did not want walls or were not satisfied for various reasons. The overall feeling of the residents appeared to be governed by the amount of noise reduction provided by the barrier. Many individual comments were received by persons concerned about things such as view, aesthetics, and cost.

Total cost of barriers per house per dB(A) ranged up to $3115; explicit barrier costs were up to $2085. The maximum cost per linear foot was $227.

ACKNOWLEDGMENT

This study was performed in cooperation with FHWA. The contents of this report reflect our views and we are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of FHWA or Caltrans and do not constitute a standard specification or regulation. A copy of the detailed report for this study is available from Caltrans.

REFERENCES

1. Federal-Aid Highway Program Manual. FHWA, FHPM 7-7-3, 8 vols., May 14, 1976.
2. T.M. Barry and J.A. Reagan. FHWA Highway Traffic Noise Prediction Model. FHWA, FHWA-RD-77-108, Dec. 1978.

# Transparent Noise Barriers Along I-95 in Baltimore City, Maryland

ROBERT D. DOUGLASS AND JEFFREY K. DRINKWATER

**The Archbishop Keough Noise Barrier Project is classified as a category 2 experimental project by the Federal Highway Administration because of the barrier material (Lexan) used in the project. Lexan, a clear plastic panel system, has never been used as a noise-abatement measure in this area and its inclusion in this project provides cost and performance information for future project comparisons. Lexan was chosen for this project because of its effectiveness in attenuating highway noise levels while at the same time not interfering with the natural, scenic vista from a highway. It was incorporated into the system of noise barriers along Interstate 95 and protects Archbishop Keough High School from elevated noise levels due to the highway. The Keough noise barrier consists of 58 transparent panels, each 10 ft high by 0.25 in thick, supported at a 7.5-ft on-center width. The panels are held in place by steel posts that are attached to a concrete footing that runs the entire 435-ft length of the project. The project was built at a cost of $151 770. The cost of the barrier itself was $87 000. Delays in the delivery of materials and our underestimation in the number of working days were not totally unexpected due to the experimental nature of the project.**

In 1968 a multidisciplinary concept team was assembled in Baltimore City, Maryland, to study its future transportation needs and problems and to recommend solutions. Environmental and aesthetic concerns were carefully evaluated by the teams of architects, engineers, and urban planners. Early in the process the need for transparent noise barriers on elevated highway sections was identified. Two benefits were attributed to transparent barriers over their opaque counterparts. The first, and most obvious, reason is that the motorists' vista and sunlight penetration to the roadway and ground are not blocked. The second benefit is that the highway and barrier would look much less imposing with a transparent barrier when viewed from the ground. On one preliminary expressway plan prepared for Interstate 83, a transparent noise barrier was shown in the area of the Canton and Fells Point communities. Even though this roadway alternative was rejected, the benefits and desire for transparent barriers remained.

As plans for I-95 progressed, the requests for transparent noise barriers on elevated expressways continued. The Interstate division staff made repeated inquiries for information on transparent barriers but were unable to find similar projects. Transparent barriers were not considered for I-95 due to unanswered questions such as,

1. Are the transparent materials available suitable for noise barriers?
2. How can they be supported?
3. How much will they cost?
4. Are there maintenance problems?
5. How will the material hold up in urban environments?
6. Will they increase reflections of sun and headlights?
7. Will they work from an acoustical standpoint?

Since our inquiries did not produce any similar projects, but we felt that the concept of transparent noise barriers was valid, we decided to look for a test project site.

THE PROJECT

The Archbishop Keough High School was identified as a potential noise-mitigation site because of elevated noise levels due to increasing traffic on I-95. Concerned school officials prompted a noise study by the Interstate division for Baltimore City. The study did, indeed, identify a noise problem once I-95 was fully opened. It was decided that, because of the pleasing vista of the school property from the highway and the limited length of barrier needed to protect the school, this project provided an ideal situation in which to implement a transparent barrier.

The Maryland Division of the Federal Highway Administration (FHWA) agreed and approved the proj-