simultaneously with traffic counting and speed monitoring, both of which were recorded by vehicle class and direction of flow. These speed and volume data were then input into the FHWA Highway Traffic Noise Prediction Model. The model predicted values 1-2 dB(A) higher than the actual monitored values. At site 9 (Figure 10), noise levels, traffic volumes, and traffic speeds were monitored simultaneously at ground level and upper stories with the barrier completed but without the absorptive surface treatment on the opposite wall. This monitoring was limited because of construction activity in the area. However, when the traffic volume and speed data were input into the FHWA model, the predicted noise levels generated were several decibels lower [3dB(A) at an elevation equivalent to top-of-barrier elevation and 5 dB(A) at ground-level-observer elevation] than the actual monitored noise levels, which indicates that reflection is likely to be a significant factor in this area. Because of the limited data, any conclusive determination of actual reflection must await further monitoring and analysis. Evaluation of the effectiveness of all of the noise barriers discussed here is expected to be completed in mid-1980.

SUMMARY

At this point, Pennsylvania's first major noise-barrier project can be termed successful. Through the late stages of construction, no major insoluble problems have emerged. Much experience has been gained in both the design and citizen-participation processes. To advance in 12 months from a stage at which there was no consensus among the many affected community groups to the construction stage was thought by many to be impossible, particularly in light of previous relations between the community and the Pennsylvania DOT. The experience gained in this process will be invaluable in future noise-barrier projects in Pennsylvania.

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Effectiveness of Noise Barriers Along the Capital Beltway (I-495) in Northern Virginia

Robert E. Armstrong

A recent Federal Highway Administration study of the effectiveness of three noise barriers along I-495 in northern Virginia is described. The study sites included (a) an earth berm, (b) a metal wall on an earth berm, and (c) a concrete wall on an earth berm. The study results, though limited in scope (no statistical analysis was performed), support conclusions reached in other studies that have attempted to validate the Federal Highway Administration's Highway Traffic Noise Prediction Model: The model provides an accurate estimate of (a) levels of unshielded traffic noise close to the roadway (7.5-15 m) and (b) levels of shielded traffic noise behind noise barriers. In addition, the results confirm that the noise barriers studied have reduced the level of traffic noise by at least 50 percent.

The use of noise barriers to reduce the impact of traffic noise on communities adjacent to highways has increased dramatically in recent years. Highway agencies across the nation are spending considerable time and money on planning, designing, and constructing these barriers on both new and existing highways. Experience has shown that noise reductions in excess of 10-15 dB are very difficult to achieve. Even after this range of reduction has been achieved by constructing a barrier, residents close to roadways are often exposed to noise levels that exceed 65 dB(A). It has been hypothesized that many people who complain of poor barrier performance are reacting to the fact that even a good barrier does not eliminate all traffic noise.

This report presents the results of a field study undertaken by the Federal Highway Administration (FHWA) to determine the effectiveness of different types of noise barriers found along the Capital Beltway (I-495) in northern Virginia. The study was conducted partly in response to citizen complaints that barriers along the

beltway did not reduce highway traffic noise.

In the past several years, FHWA has developed methodologies to measure and predict levels of traffic noise and design noise-abatement measures. The most common method for assessing how well prediction methods accomplish their purpose is to compare predicted levels of traffic noise with levels measured in the field. The study reported in this paper involved the use of these methods.

The procedures used in the study are readily available to state highway agencies and interested individuals. The measurement procedures used are described in an FHWA interim report (1) (procedures presented in the interim report for measuring barrier insertion loss are being validated and were not used in this study, but procedures found in the report for taking sound-level measurements were used). The prediction procedures used are described in another FHWA report (2).

MEASUREMENT PROCEDURE

The effectiveness of a noise barrier is determined by measuring or calculating its insertion loss—that is, the noise reduction provided by a barrier at any given point. Numerically, this measurement is equal to the difference in sound levels at a given point with and without a barrier. The ideal would be to measure sound level before and after the construction of a barrier, under identical conditions. Unfortunately, this is often not possible, and so it becomes necessary to calculate the "before" sound level by using an analytical highway traffic noise prediction model. Since the noise barriers evaluated in this study were already in place, STAMINA, a computerized version of the FHWA Highway Traffic Noise Prediction Model, was used to calculate before sound levels.

Before using the FHWA model to make predictions and calculations, a user should evaluate how well the model simulates real-world conditions. Adjustments to the model may be necessary. To do this, the noise emission model and a combination of the emission model, the propagation model, and the barrier attenuation model can be checked simultaneously by comparing calculated sound-level values with measured values. If this com-

parison shows close agreement between the values, no adjustment to the model is necessary and the before sound level can be calculated.

In this study, measurements of existing sound levels were taken in front of, above, and behind the noise barriers. Two sets of measurements were taken at each study site. One microphone position varied between the two sets. At each microphone position, sound levels were recorded every 10 s by using type 1 sound-level meters; 100 samples were taken, and a 95 percent confidence level for the data was obtained.

During each set of measurements, vehicles traveling in each direction were counted and classified into categories of automobiles, medium trucks, and heavy trucks. In one location, traffic was recorded for only one direction because only one direction of the travel lanes was contributing to the noise being measured. Average speeds for automobiles and trucks were determined separately by using radar equipment.

STUDY SITES

In order to evaluate different types of barriers in the I-495 corridor, three sites were chosen for the study. Figure 1 shows the geographic location of the sites, which can be described as follows:

1. Site A—metal wall on earth berm, located 7.6 m above the roadway on Leesville Boulevard (see Figures 2 and 3);
2. Site B—earth berm alone, located 5.1 m above the roadway on Helena Drive (see Figures 2 and 4); and
3. Site C—concrete wall on earth berm, located 5.3 m above the roadway on Cabin John Road (see Figures 5 and 6).

Table 1 gives data on microphone positions and traffic volume and speed for each site.

DATA PROCESSING PROCEDURES

As previously stated, barrier effectiveness is determined by measuring insertion loss, which is numerically equal to the difference in sound levels at a given point
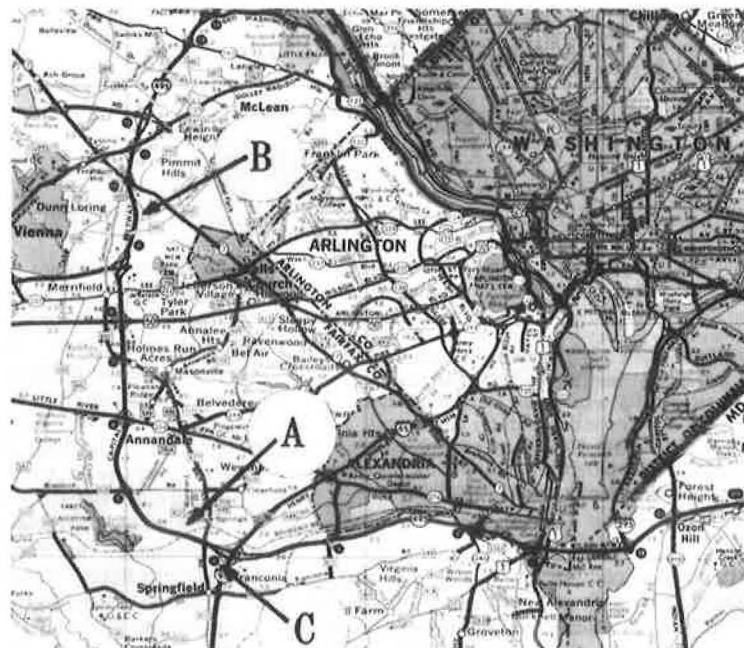
Figure 1. Location of I-495 study sites.

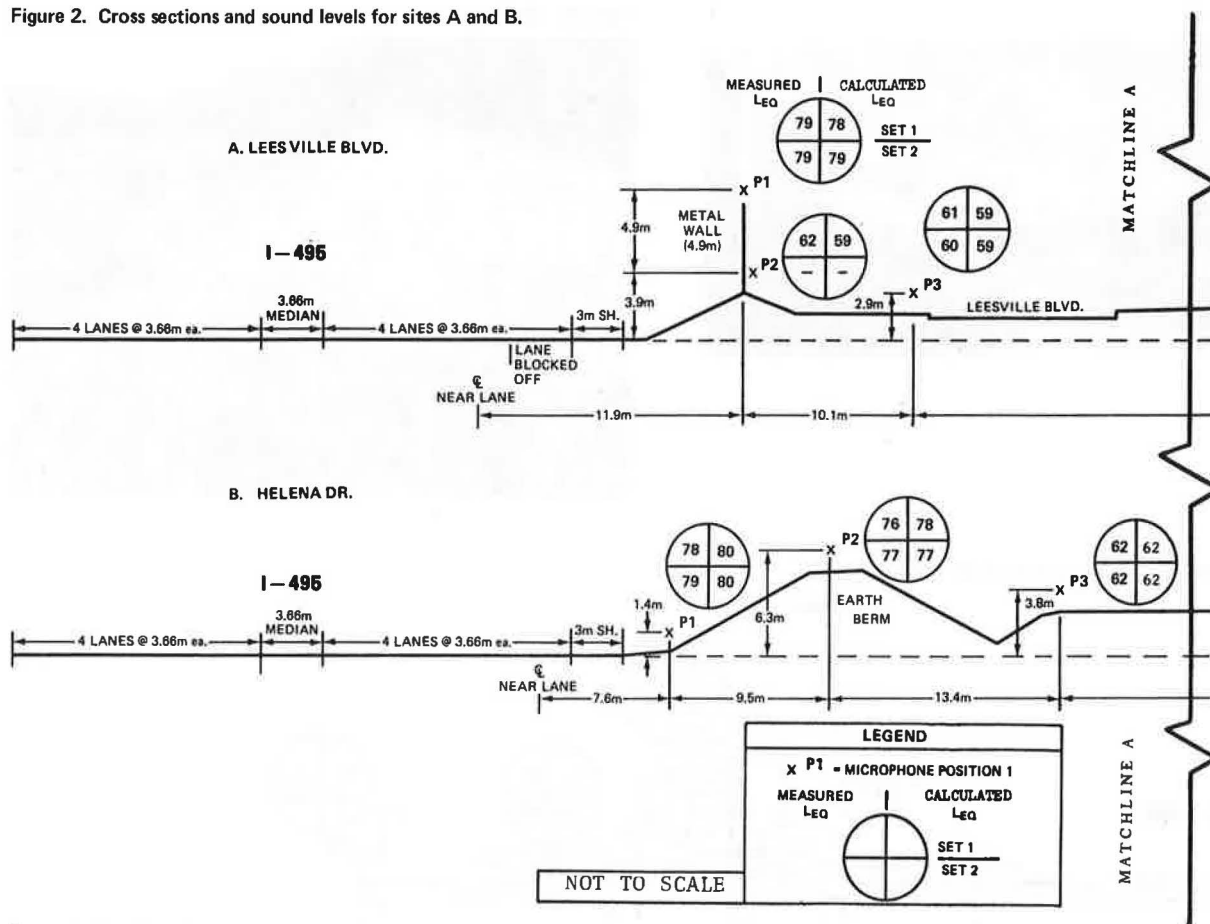Figure 2. Cross sections and sound levels for sites A and B.

Figure 2. Continued.
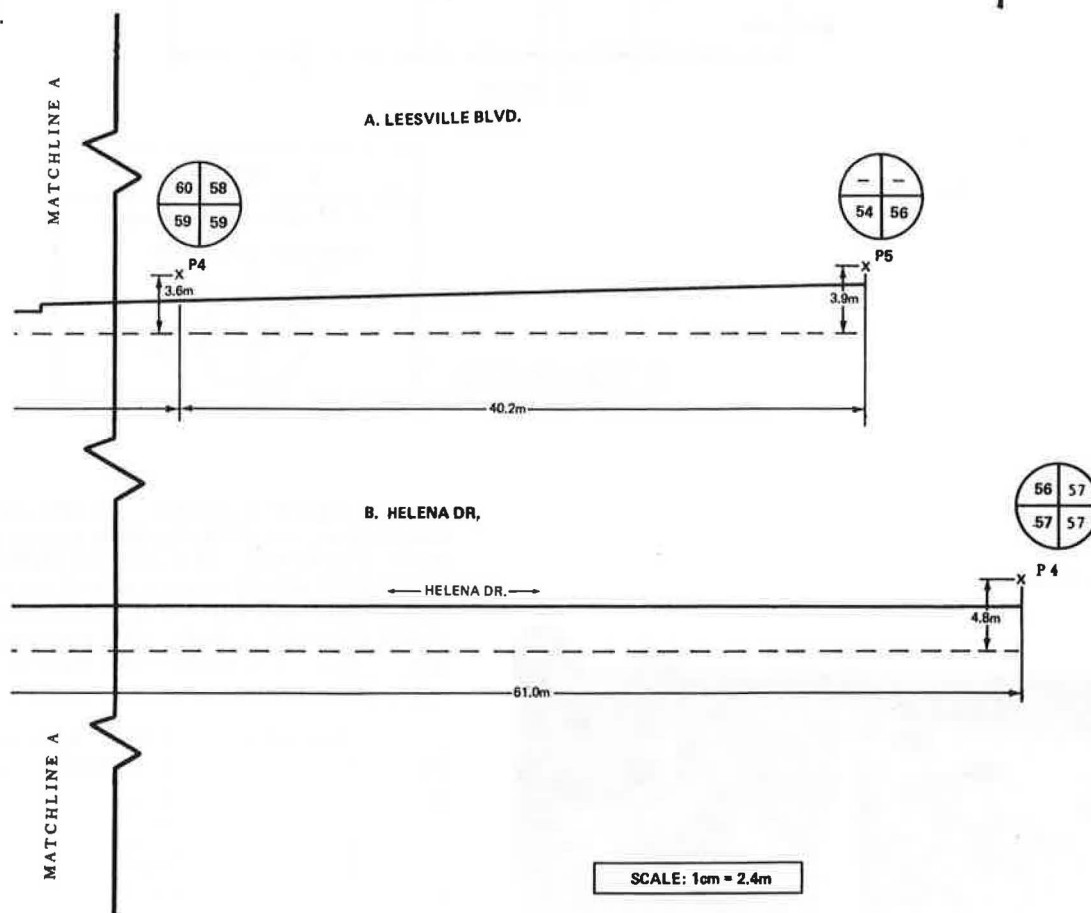
Figure 3. Site A.

Figure 4. Site B.

Figure 5. Cross section and sound levels for site C.

C. CABIN JOHN RD.
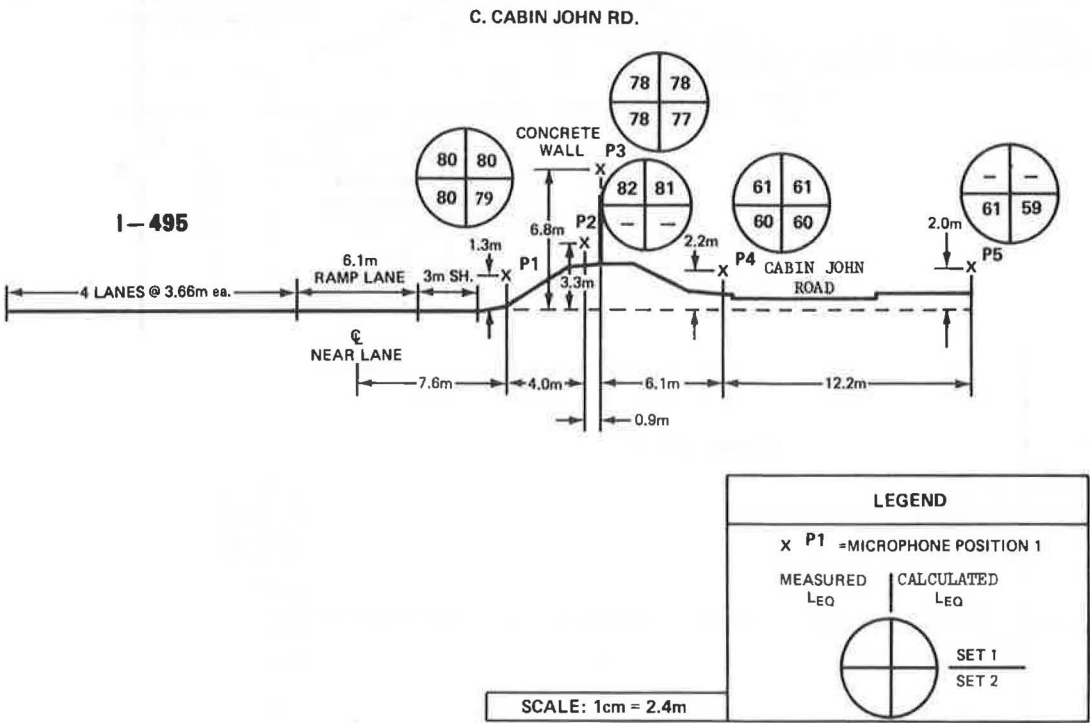
Figure 6. Site C.

with and without a barrier. By using the procedure outlined above, the FHWA highway traffic noise prediction model (STAMINA) was found to be sufficiently reliable to calculate before sound levels at the study sites. The values given in Table 2 support this finding, as do the values given in the table below (the amounts by which calculated L_{eq} values were less than or more than measured values):

Site	Measurement Set	Difference Between Calculated and Measured L_{eq} (dB)
A	1	-1 to -3
	2	-1 to +2
B	1	0 to +2
	2	0 to +1
C	1	0 to -1
	2	0 to -2

Table 1. Microphone positions and traffic characteristics for study sites.

| | | Distance (m) from Centerline of Near Lane to | | | | | | Daily Traffic Volume[a] | | | Average Speed (km/h) | |
| | | | Microphone Position | | | | | | Trucks | | | |
Site	Measurement Set	Barrier	P1	P2	P3	P4	P5	Automobiles	Medium	Heavy	Automobiles	Trucks
A	1	11.9	11.9	12.2	22.0	42.1		4380	312	340	83.2	83.2
	2	11.9	11.9		22.0	42.1	82.3	4476	400	392	83.2	81.6
B	1	17.1	7.6	17.1	30.5	91.5		4528	288	340	84.8	78.4
	2	17.1	7.6	17.1	30.5	91.5		4184	268	364	83.2	75.2
C	1	12.5	7.6	11.6	12.5	18.6		3112	172	256	84.8	81.6
	2	12.5	7.6		12.5	18.6	30.8	2640	172	192	81.6	78.4

[a]During field measurements.

Table 2. Calculated and measured sound levels.

| | | Sound Level by Microphone Position [dB(A)] | | | | | | | | | |
| | | P1 | | P2 | | P3 | | P4 | | P5 | |
Site	Measurement Set	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured
A	1	78	79	59	62	59	61	58	60		
	2	79	79			59	60	59	59	56	54
B	1	80	78	78	76	62[a]	62	57[a]	56		
	2	80	79	77	77	62[a]	62	57[a]	57		
C	1	80	80	81[b]	82	78	78	61	61		
	2	79	80			77	78	60	60	59	61

[a]Calculated sound levels reduced by 3 dB(A) because of added attenuation caused by earth berm.
[b]Calculated sound level includes reflections from wall.

Table 3. Before (calculated) and after sound levels.

		Sound Level by Microphone Position [dB(A)]												
		P1		P2		P3			P4			P5		
							After			After			After	
Site	Measurement Set	Calculated	Measured	Calculated	Measured	Before	Calculated	Measured	Before	Calculated	Measured	Before	Calculated	Measured
A	1	78	79	59	62	74	59	61	71	58	60			
	2	79	79			75	59	60	72	59	59	68	56	54
B	1	80	78	78	76	73	62[a]	62	67	57[a]	56			
	2	80	79	77	77	73	62[a]	62	66	57[a]	57			
C	1	80	80	81	82		78	78	75	61	61			
	2	79	80				77	78	74	60	60	71	59	61

[a]Calculated sound levels reduced by 3 dB(A) because of added attenuation caused by earth berm.

Table 4. Insertion loss.

| | | Insertion Loss by Microphone Position [dB(A)] | | | | | |
| | | P3 | | P4 | | P5 | |
Site	Measurement Set	Calculated	Measured	Calculated	Measured	Calculated	Measured
A	1	15	13	13	11		
	2	16	15	13	13	12	14
B	1	11	11	10	11		
	2	11	11	9	9		
C	1			14	14		
	2			14	14	12	10

The STAMINA model is based on a reference energy mean emission level, to which adjustments are made to account for traffic flows, varying distances from the roadway, finite-length roadways, and shielding.

Since the installation of a noise barrier at a site negates any attenuation attributable to such factors as grass or shrubs, a propagation loss factor of 3.0 dB/doubling of distance was used in all calculations involving barriers. A manual reduction of 3 dB(A) was made for the sound levels calculated behind the earth berm at site B because past studies have indicated that earth berms provide approximately 3 dB(A) more noise attenuation than do barrier walls. Since all the sites were covered with grass and small shrubs, a propagation loss factor of 4.5 dB/doubling of distance was used to calculate the before sound levels. This results in a more conservative barrier insertion loss than would assumption of a 3.0-dB factor, since the calculated before sound levels are lower. Table 3 gives values for the calculated (before) and measured sound levels at the study sites.

ANALYSIS OF RESULTS

Table 4 gives the insertion losses determined for each study site. An insertion loss of 10 dB(A) is usually achievable with barriers of reasonable height and length; a 15-dB(A) insertion loss is much more difficult to obtain. A review of the values in Table 4 shows that insertion losses at the I-495 study sites range from 9-15 dB(A). It can be seen that the barriers at the study sites are producing acceptable insertion losses, reducing loudness at the sites by at least a half [10 dB(A)].

All three types of barriers appear to be performing

well. Because of differences in site geometry, barrier
design, and traffic conditions, it is not possible to say
that one barrier type is performing better than another.
However, the study data do support the position that
earth berms provide approximately 3 dB(A) more at-
tenuation than barrier walls.

CONCLUSIONS

Although this study was limited in scope (no statistical
analysis was performed), the results support two con-
clusions that have been reached in other studies that
have attempted to validate the FHWA Highway Traffic
Noise Prediction Model:

1. The FHWA model provides an accurate estimate
of the unshielded traffic noise levels close to the road-
way (7.5-15 m). This is essentially a test of the vehicle
emission data used in the model.

2. The FHWA model provides an accurate estimate
of the shielded noise levels behind noise barriers. This
is a test that involves the emission model, the attenua-
tion rate with distance propagation loss, and the barrier
attenuation model.

In addition, the results confirm that the noise barriers
studied are effective in reducing levels of traffic noise.

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Systematic Method for Prioritizing Barrier Retrofit Projects for Highways

Louis F. Cohn

Because there is no standardized method for prioritizing highway
noise-barrier retrofit projects, states that have such programs have
had to develop their own. The methods of four states that have
established ongoing noise-barrier retrofit programs—Minnesota,
Maryland, Connecticut, and California—are examined. A compre-
hensive method developed by the New York State Department of
Transportation (NYSDOT) is analyzed in detail. The seven-phase
New York procedure relies heavily on field reconnaissance. A pre-
liminary listing of potential projects is developed by computer
analysis early in the process, and this listing is then refined several
times as new information is gathered. The final outcome of the
method is a list by NYSDOT region that shows potential projects
by L_{10} "zone" [zone 1 for L_{10} values greater than 80 dB(A), zone
2 for values of 75-80 dB(A), and zone 3 for values of 70-75 dB(A)]
and indicates a cost/benefit surrogate per project site. The cost/
benefit surrogate selected is square meters of barrier required ver-
sus number of receptor units protected.

In 1967, New York became the first state to consolidate
its highway, rail, aviation, and waterway responsibili-
ties into one agency, the New York State Department of
Transportation (NYSDOT). Since that time, NYSDOT
has been a leader in developing many of the analytical
tools now in use in the transportation profession, in
areas as diverse as traffic safety research and trans-
portation planning techniques.

One area in which NYSDOT has chosen not to be in
the forefront, however, is the construction of noise-
barrier systems on existing highways (retrofit). There
are several reasons for this decision. First and most
important, as the federal retrofit program was matur-
ing into full implementation, the state of New York was
entering an extended period of fiscal restraint. During
the years 1975 and 1976, the state governmental struc-
ture was close to economic chaos as a result of the
imminent default of New York City. Default was averted,

but the whole experience created cutbacks and delays in
many state programs. Once economic recovery was
under way, NYSDOT became committed to a new pro-
gram of high-yield capital construction that could be
used to stimulate the state economy. In FY 1977/78,
NYSDOT's highway construction budget exceeded $700
million, nearly double previous levels (1). This type of
emphasis was not conducive to the implementation of
noise-barrier retrofit projects, which require con-
siderable planning but add little to the capital program.

A second major reason for the conservative efforts
of NYSDOT in this area is that the potential for over-
commitment is so great. New York State, with its
population of nearly 20 million, has more than 2260 km
(1400 miles) of highways designated as Interstates.
Preliminary field studies have indicated that there are
hundreds of potential sites for noise barriers in the
state and that the associated cost is in the scores of
millions. As a result, NYSDOT administrators have
required an assessment of the magnitude of retrofit cost
before approving a major program.

Last, in New York only a minimal number of com-
plaints about excessive highway noise levels have been
received from residents adjacent to highways. The two
exceptions to this are in Westchester and Duchess
Counties in the vicinity of I-684 and I-84 and in the
Buffalo area along I-290 (the Youngmann Expressway).
In the Westchester County situation, the residential
properties are typically so large and population densi-
ties so low that using barriers to reduce noise is gen-
erally not cost-effective.

The Youngmann Expressway in Buffalo, on the other
hand, does present an excellent opportunity for noise
reduction. The area adjacent to the highway has gen-