HIGHWAY NOISE REDUCTION BARRIERS
A LITERATURE REVIEW

by

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SUMMARY

This report describes the various parameters that must be considered in evaluating highway noise barriers. The information presented is based on the current state of the art and covers the effectiveness, designs, materials and costs of barriers.

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INTRODUCTION

Noise has been increasing in recent years, and the growing environmental concern has made nearly everyone more aware of this fact. Highway traffic is one of the sources of this noise. The increase in highway generated noise is caused by: the increased number of motor vehicles, a denser concentration of traffic on major highway routes, and the increased use of land near highways to fill the residential and commercial needs of a growing population. [1]

In response to the concern over highway noise, the Federal Highway Administration issued Policy and Procedure Memorandum 90-2, which requires that highway design personnel consider use of noise reduction devices on certain highway construction projects. In meeting the FHWA requirements, the engineer has several approaches open, including: a reduction of the noise generated by motor vehicles, improvements in highway design and location, and proper zoning of land adjacent to highways. [2]

So proper highway design and location is but one of at least three ways to reduce highway noise. However, as is obvious, it is the primary approach to highway department noise reduction planning. In one facet of this approach, highway noise barriers are one of the main tools used to reduce noise.

PURPOSE AND SCOPE

To provide Virginia Department of Highway planners with the latest information on highway noise barriers, a literature search was conducted to analyze the present designs, costs, and performances of actual highway noise barriers.

M. J. Kodaras and Associates, acoustic consultants, have published the most recent literature review on noise barriers. [3] The Kodaras review found that most of the studies on highway noise have been published during the past 20 years, with very little worthwhile information having been published before 1952 and the most valuable contributions having been made in the last two to three years.

The Kodaras literature abstracts cover both the theory of barrier noise reduction and actual barrier construction. The theoretical studies reviewed by Kodaras and researched by this writer are not discussed in this paper. It is beyond the scope of this report to analyze the numerous and complex theoretical noise barrier reduction studies available in the literature. However, these reports are listed in the selected references.

Highway designers concerned with noise reduction have at their disposal the following FHWA approved models: NCHRP 117, Highway Noise — A Design Guide for Highway Engineers (4) and the TSC Manual for Highway Noise Prediction (5) for predicting highway noise reduction levels for various effective barrier heights. These models have incorporated the best theoretical concepts of the present research as determined by the acoustical experts who derived them. Research reports on noise barrier construction from the Kodaras report and additional research reviewed by this writer are discussed to set forth some basic principles of barrier attenuation of traffic noise and to show the general trends in barrier construction.

SOME BASIC PRINCIPLES OF BARRIER ATTENUATION OF TRAFFIC NOISE

This section of the report was taken from Fundamentals and Abatement of Highway Traffic Noise, published by Bolt Beranek & Newman, Inc. to train interested personnel in highway noise prediction and abatement. (6)

"Noise emanating from the source (see Figure 1) can follow four paths that are important for highway noise barrier evaluation.

"The traffic noise follows a direct path to receivers who can see the traffic well over the top of the barrier. The barrier does not block their line-of-sight and therefore provides no attenuation. No matter how absorptive the barrier is, it cannot suck the sound downward and absorb it.

"The noise follows a diffracted path to receivers in the shadow zone of the barrier. The noise that passes just over the top edge of the barrier is diffracted (bent) down into the apparent shadow shown in Figure 1. The larger the angle of diffraction, the more the barrier attenuates the noise in this shadow zone. In other words, less energy (i.e., less noise) is diffracted through large angles than is diffracted through the smaller angles. In the shadow zone, the noise transmitted directly through the barrier may be significant in some cases. For example, for extremely large angles of diffraction, the diffracted noise may be less than the transmitted noise. In this case the transmitted noise is compromising the performance of the barrier, and it must be reduced — usually by constructing a heavier barrier. The allowable amount of transmitted noise depends upon the barrier attenuation desired.

"The final path in Figure 1 is the reflected path. After reflection, the noise is of concern only to a receiver on the opposite side of the roadway, across from the barrier. For this reason, acoustic absorption on the face of the barrier will reduce this reflected noise, but will not benefit any receivers in the shadow zone. Their noise is diffracting over the top of the barrier, unaffected by the absorption.

"In summary a receiver in the shadow zone hears the noise that has diffracted over the top of the barrier. The resulting noise level is less than it would be without the barrier; the net benefit is called the "barrier attenuation". If the barrier transmits an excessive amount of noise, this transmitted noise may "short-circuit" (i. e. significantly reduce) the barrier attenuation.

"Another short-circuit path is shown in Figure 2, a plan view of the same barrier. The noise diffracted over the top of the barrier is reduced by the barrier attenuation. However, part of the roadway is unshielded by the barrier. The receiver can see the roadway beyond the ends of the barrier, up and down the corridor. If the barrier is not long enough, then this noise from around the ends may compromise, or short-circuit, the barrier attenuation. The required barrier length depends upon the net attenuation desired. When some 10 to 15 dBA attenuation is desired, roadside barriers must be very long. . . . Therefore, barriers must not only break the lines of sight to the nearest section of roadway, but also to the roadway far up and down the corridor."

For additional review of general outdoor highway noise acoustics, the reader is referred to D. F. Noble's report on this subject. (7)

EXPERIMENTAL RESEARCH AND EVALUATION

Based on the available published research, with the exception of California, the states are just beginning to construct noise barriers. In contrast to this, both Great Britain and Ontario have done major studies involving the construction and evaluation of highway noise barriers.

In Great Britain, a 300-meter plastic barrier was built near London in 1971 at a cost of $200/meter. (8) The literature also mentions that similar barriers, but made of concrete, have been constructed near Berlin and Paris at similar cost. (9) The expected attenuation due to these barriers is not given.

Probably the most extensive report to date is that on barrier construction and evaluation by the Ontario Department of Transportation. (10) The Ontario study was done because "few, if any, full-scale field tests of noise barriers adjacent to freeways had been carried out elsewhere. . ." Their preliminary cost estimates showed that at $25 to $50 per foot for a 10-ft. barrier, or $125,000 to $250,000 per mile, noise barrier

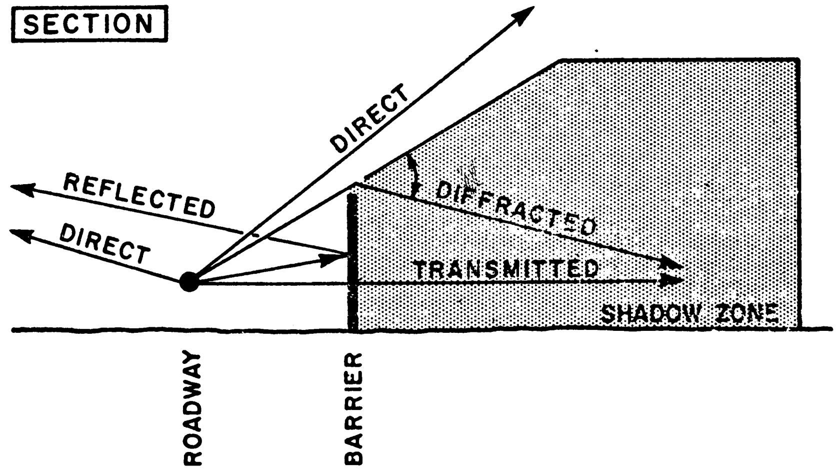

Figure 1. Noise paths from roadway to receiver

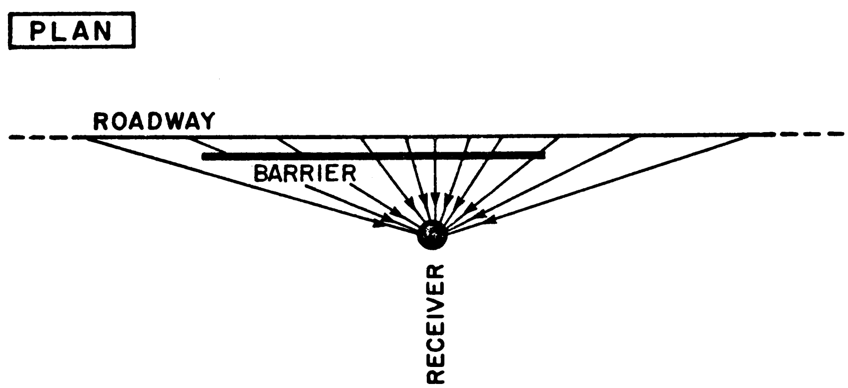

Figure 2. Short-circuit of barriers around ends

construction was quite expensive.* Tables 1 and 2, taken from the Ontario study, show the costs per foot of barriers constructed of different materials. Though Canadian materials and labor costs in relation to those in the United States are unknown, the Ontario study should provide a relative cost comparison for each of the materials that was used. However, due to effective height restrictions based in part on snow drifting considerations, they obtained only minimal results, a 2 to 6 dBA reduction at the receiver.

Since the Ontario work, few states have attempted to conduct studies of the same magnitude. California is a notable exception. The California Department of Highways has been constructing noise barriers along some of their freeways for years.

The following paragraphs were taken from a paper by W. R. Green, highway design engineer for the California Division of Highways. (11) They present a general overview of the California Division of Highways' policy on noise abatement.

"We believe that noise barriers should be provided only as a last resort, as they result in undesirable as well as desirable effects. Some of the undesirable effects are creation of a fixed object, possible tunnel effect, and cost. Our present noise control policy in California and the proposed Federal policy recognize that when development occurs subsequent to location of the freeway, the responsibility for noise attenuation rests with others. When it is the road building agencies' responsibility to shield existing noise sensitive developments from excessive noise, protection can oftentimes be provided for less cost by acquiring an extra wide right-of-way, changing the freeway alignment to avoid the developed areas or by depressing the freeway.

"The noise barriers we have built have consisted primarily of concrete block or a combination of concrete block and earth mound. These are not always the most economical type of barrier to provide. Full earth mounds will usually be the most attractive and least expensive noise barriers if sufficient embankment material and right-of-way are available." (12)

In 1971, the California Department of Highways began a study of additional materials and methods which could be used in the construction of noise barriers. (13) The purpose of this study was to find alternative materials of less cost, but which would not result in a sacrifice in safety or aesthetics. Table 3 lists the materials that were analyzed.

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* These costs are somewhat misleading if taken at face value. Additional cost considerations such as the contractor's unfamiliarity with the material, breakage precautions, material requirements, and construction site work restrictions are included.

TABLE 1

Barrier Types and Characteristics (from Reference 10)

BARRIER DESCRIPTION (ALL 10' HIGH)	COST PER LINEAR FOOT	MAINTENANCE	CONSTRUCTION TIME AND FEATURES	REMARKS
1. EARTH MOUND 3:1 SIDE SLOPES	$ 2 - 4	GRASS CUTTING, PLANTING	IMMEDIATE CONSTRUCTION; TRUCKING TRAFFIC CONFLICT	APPLICATION DEPENDENT ON R/W AVAILABILITY
2. CONCRETE BLOCK	$ 20	MINIMAL	LENGTHY CONSTRUCTION TIME; MINIMUM OF EQUIPMENT	POOR APPEARANCE
3. TIMBER OR PLYWOOD	$ 20	PAINTING	LENGTHY ERECTION TIME	NOT ANTICIPATED TO BE SOUND OPAQUE
4. LEAD LAMINATE	$ 20 - 30	MINIMAL	FAST ERECTION AFTER QUICK SHOP FABRICATION	PRICE RANGE TO COVER THICKNESS OF LEAD REQUIRED, TO BE DETERMINED BY EXPERIMENTATION
5. BRICK WALL	$ 30	MINIMAL	LENGTHY CONSTRUCTION TIME; MINIMUM OF EQUIPMENT	PLEASING APPEARANCE
6. NEW JERSEY BARRIER	$ 30	NORMAL	MINIMAL IF PRECAST	ONLY TYPE APPLICABLE TO FILLS OVER 5' - 10' HIGH
7. ARMCO BIN WALL	$ 40	MINIMAL	FAST ERECTION WITH "IN STOCK" MATERIALS	CORRUGATED PANELLING INFILLED WITH EARTH
8. PRE-CAST CONCRETE	$ 40	MINIMAL	FAST ERECTION	PRICE BASED ON 6" THICK 25' LONG PANELS
9. IN-SITU CONCRETE WALL	$ 50	MINIMAL	SLOW CONSTRUCTION REQUIRING HEAVY EQUIPMENT	NORMAL FORMING 9" THICK

TABLE 2

Description of Noise Barriers (from Reference 10)

TYPE NO.	BARRIER DESCRIPTION	THICKNESS INCHES	HEIGHT	TOTAL LENGTH FEET	TYPE OF SUPPORT	MATERIAL OF THE BARRIER	ACTUAL* COSTS PER LINEAR FT.,$	APPROXIMATE* COSTS PER LINEAR FT. OF 10' HIGH BARRIER,$
1	PRE-CAST CONCRETE WALL	6	8'6" to 11'	2021	CONCRETE "H" COLUMNS 25' APART	REINFORCED CONCRETE 4000 PSI AT 28 DAYS	48	42
2	EARTH BERM	60 ON TOP	9' to 10'	1010	—	EARTH FILL, TOPSOIL, SODDING	25	25
3	PRE-CAST CELLULAR CONCRETE WALL	6	8'6"	800	STEEL COLUMNS 8123 20' APART	REINFORCED CONCRETE 600 PSI AT 28 DAYS DENSITY 35 LB/FT^3	44	55
4	PRE-CAST CELLULAR CONCRETE WALL, ON TOP OF EARTH BERM 5'TO 8' HIGH	4	3'6" to 7'6"	1650	STEEL COLUMNS 6I 12.5 10' APART	REINFORCED CONCRETE 600 PSI AT 28 DAYS DENSITY 35 LB/FT^3	36**	36
5	PRE-CAST CELLULAR CONCRETE WALL	4	9'	690	STEEL COLUMNS 6I 12.5 10' APART	REINFORCED CONCRETE 600 PSI AT 28 DAYS DENSITY 35 LB/FT^3	41	45
6	ALUMINIUM WALL	3	8'***	720	ALUMINIUM "H" COLUMNS 18' APART	1/8" ALUMINIUM PLATE	40	40
7	WOODEN WALL	3/4	9'	400	STRUCTURE ATTACHED TO FENCE	TREATED FIR PLYWOOD PANELS	12	15
8	GABION WALL	36	8'***	810	—	ROCK IN WIRE BASKET	80-90	60
9	POREX CONCRETE WALL	4	12'	1400	STEEL COLUMNS 10' APART	REINFORCED LOW DENSITY CONCRETE 40 LB/FT^3	35	30

* EXCLUDES COSTS OF ENGINEERING AND RELOCATION OF SEWERS
** 5' HIGH WALL + 5' HIGH EARTH BERM
*** ABOVE EDGE OF PAVEMENT

TABLE 3

Analysis of Possible Barrier Materials

Materials	Dimensions	Cost	Aesthetic and Other Properties
Precast concrete panels	4" x 10' x 16'	$1.50/sq. ft.	Available in varying textures and colors
Chain link fence with plaster	Unknown	$5.00/lin. ft.	Use along existing freeways
Plaster wall (proposed)	See Figure 3	Unknown	Variety of textures and colors
Kaiser steel wall (proposed)	See Figure 4	Unknown	May be attached to concrete safety barriers or metal beam guardrails
Corrugated asbestos cement panel (proposed)	6' height or greater	Unknown	Different colors available

The materials in Table 3 could have possible use in noise-reduction barriers, especially where right-of-way is limited and certain aesthetic considerations should be evaluated. California has constructed some walls of precast concrete panels and chain link fence with plaster for these reasons. It is unknown whether the proposed plaster wall (see Figure 3), the Kaiser steel wall (see Figure 4), and the corrugated asbestos cement panel have actually been used for highway noise barriers. The plaster wall and the Kaiser wall (Figures 3 and 4), each of which needs little or no additional right-of-way, could have possible application depending on cost. The plaster wall consists of a 7/8" portland cement coating on a wood or metal frame. (14) The Kaiser steel wall is constructed of 20 gauge corrugated steel for heights up to six feet, and can be attached to concrete safety barriers or metal guardrails. (15) It is not known whether these materials have actually been field tested for noise reduction values.

California, having constructed noise barriers for sometime, uses a basic design approach to highway noise reduction. Assuming adequate effective barrier height and density, the California Department of Highways has predominately used earth berms where right-of-way is available. If right-of-way is not available, concrete and concrete blocks are used.

In addition, California has conducted extensive noise level readings on the noise reductions caused by various geometries of depressed and elevated highways, both shielded and unshielded. This reader is again referred to D. F. Noble's report (16) on this subject.

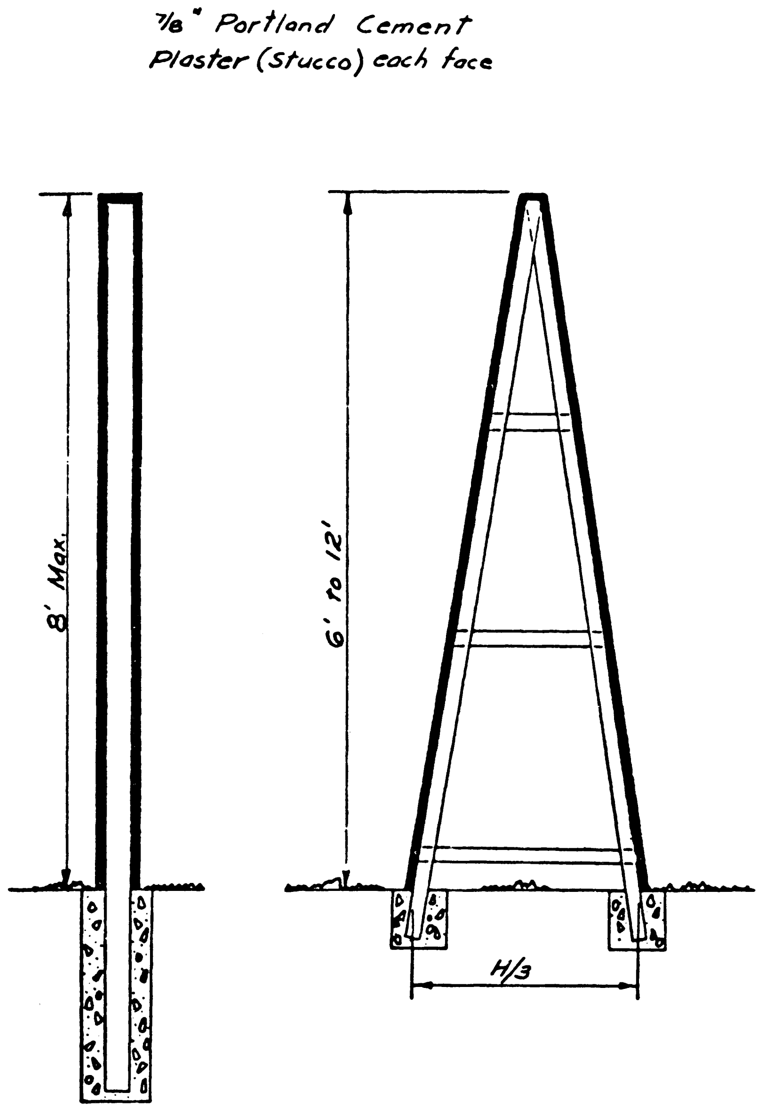

Figure 3. Plaster wall sound barrier (from Reference 2)

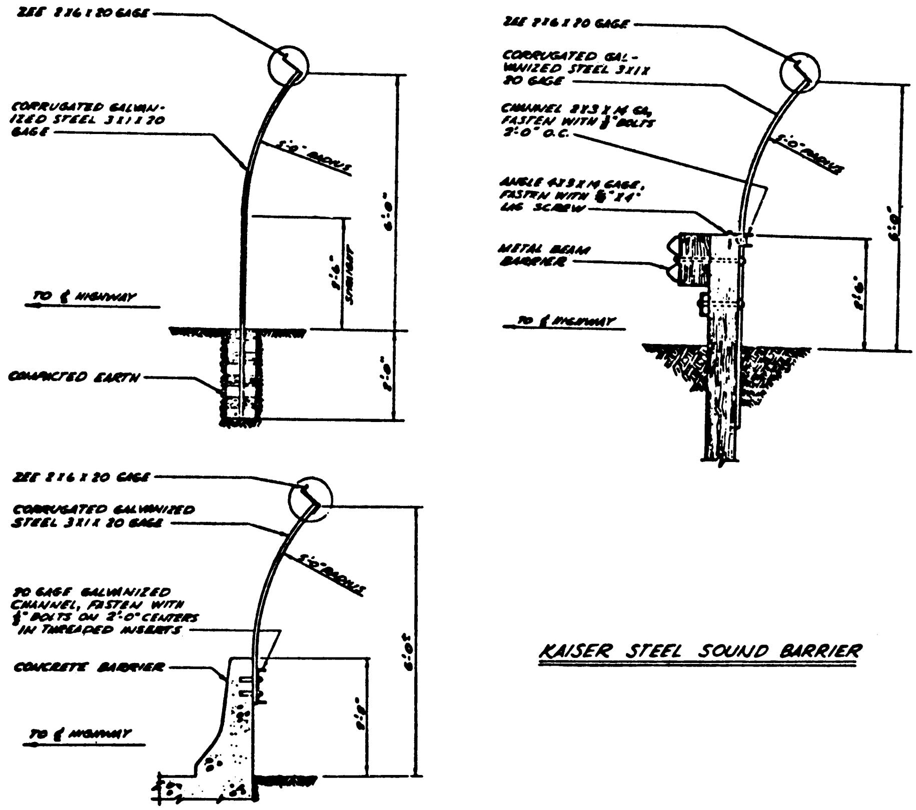

Figure 4. Kaiser steel sound barrier (from Reference 2)

Based on the available research, the only other states which have actually constructed noise barriers are Maryland, Minnesota and Texas.

The Maryland Department of Transportation, working with the acoustic consultant firm of Bolt Beranek and Newman, Inc., has recommended the use of earth berms, earth berms topped with corrugated steel walls, and clear plastic acrylic screens to reduce noise along sections of the 26-mile interstate highway system for Baltimore City. [17, 18] Earth berms constructed from construction cut-and-fill were estimated to be the most economical. At present, one of the earth berms is being built, based on noise level reduction techniques presented in NCHRP Report #117. Predicted noise level reductions were not given. It is expected that these barriers will add an additional 0.5% to the total construction costs. Actual barrier construction costs were not given. [19]

In 1972, the Minnesota Department of Highways began construction of a 1,910-ft. wooden and earthen sound barrier. This barrier was constructed to reduce noise along a section of completed interstate highway in South Minneapolis. It was constructed at a cost of approximately $345,000. It consists of a wooden wall on a soil mound to reduce the height of the wall, which varies from 5 to 19 feet. Fir posts 6" x 6" and 6" x 12", with spacings of 8 and 6 feet, are being used. The wall facing is 2" x 8" pine board on both sides. Environmental considerations to reduce the visual impact of the wall have also been included. These factors include gradual curving of the horizontal alignment, application of a greenish hue to the wooden parts of the wall, and mass plantings to naturalize the slope areas and integrate the wall into the landscape. The noise barrier walls were designed by acoustic consultants to provide a 10 - 15 dBA noise level reduction at the first story level of homes adjacent to and fronting the interstate highway. [20] It is unknown whether this level of noise reduction was actually achieved.

A concrete barrier of variable height was built along sections of the Dallas North Tollway in Texas to shield residential areas. Costs and noise reduction levels for this wall are unknown.

It would appear from the literature that the previously mentioned states are conducting their own research, sometimes with the aid of consultants, to solve their specific highway noise problems.

Limited quantitative information is available on actual highway noise barrier sound level reductions, because most of the previously mentioned highway organizations are in the preliminary phases of this area of noise research. However, certain recurring factors are already evident and thus can be applied to highway noise barrier construction.

Assuming that a barrier material density of 4 lb. per sq. ft. is established to prevent noise transmission through the barrier, the total cost of the barrier material and its installation is the prime consideration. This is exemplified in the previously mentioned California study of possible barrier materials.

In terms of cost, with proper planting, the earth berm is generally the most economical, maintenance free, and aesthetically pleasing type of barrier. However, earth berms require a greater right-of-way than other barrier forms such as a concrete wall. The additional land cost must be weighed against possible noise complaints and the less aesthetic concrete type wall.

Earth berms, to be economical, must be considered during the design stage of a new highway, in terms of the excess cut-and-fill. The Minnesota barrier illustrates this point. The fill required to build sections of the Minnesota barrier had to be supplied from another source, since any excess cut material excavated during highway construction had already either been utilized or removed.

As for other possible barrier material, cost, as previously mentioned, is the primary consideration, but other factors such as maintenance and durability must be evaluated for overall long-term cost.

With the exception of earth berms, another acoustic aspect which must be considered is the reduction of noise from reflective barriers (i.e. certain concrete type barriers). This is a complex problem, which, in the present state of the art, has not been completely evaluated. Reflected noise from a barrier can be reduced to varying extents depending upon the absorption coefficient of the barrier wall material.

The following section, taken from the previously mentioned Bolt Beranek and Newman text, (12) explains the use and limitations of absorptive noise barriers.

"For a full answer, the absorption coefficient must be known as a function of frequency. Then the traffic spectrum (most importantly the truck spectrum) is reduced by the absorption at each frequency to obtain the reflected spectrum. After the A-level of this new spectrum is calculated, it is compared to the original A-level to obtain a reduction in dBA. This procedure is cumbersome, and can generally be simplified as described below.

"A single-number absorption coefficient is catalogued by the Acoustical and Insulating Materials Association. This single-number coefficient is called the Noise Reduction Coefficient, NRC. It is an average of the absorption coefficients in the frequency region from approximately 200 to 3000 Hz.

NOISE REDUCTION COEFFICIENT

$$NRC = \frac{ABS_{250\ Hz} + ABS_{500\ Hz} + ABS_{1000\ Hz} + ABS_{2000\ Hz}}{4}$$

where ABS = Sound Absorption Coefficient

"Since these frequencies are most important in speech communication, and since the A-level of traffic noise is controlled by the energy in this frequency region, we can use this single number NRC. For any NRC, the reflected noise level is reduced by the amount shown in Table 4.

"If a barrier wall is absorptive, then the reflected level should be reduced by the amount in the table. Nothing else is changed in the calculation.

"It is necessary that barrier absorption be 'broad band'. In other words, the barrier should absorb energy over a broad range of frequencies. Most absorptive surfaces do have broad-band absorption, with correspondingly large NRC's. Some structures however, only absorb energy in narrow frequency bands. Such structures include Helmholtz resonators and similar resonant-cavity structures. Such structures leave most of the energy unabsorbed, and have resultingly low NRC's. The bulk of the broad-band traffic noise will not be absorbed, and the A-level will be reduced very little.

Receivers Opposite the Barrier

"How important is this reflected noise for receivers opposite the barrier? When the direct noise is blocked by a barrier, then the unblocked, reflected noise can control. In such cases, barrier absorption can significantly benefit the receiver. When the direct noise is not blocked however, then the reflected noise can add 3 dBA* at most, since at most it can double the energy at the observer. Usually it does not fully double the energy, since the reflected noise has further to travel to the receiver. With no absorption, the resulting increase is usually not significant; little benefit would be derived from making the barrier absorptive.

"For depressed roadways, with vertical retaining walls on each side, multiple reflections may be important. Insufficient information is known about this phenomenon to estimate the reverberant build-up and resultant spillage of noise out of the depression."

Additional inquiries to major acoustical material suppliers [22] and further comments by Bolt Beranek and Newman, Inc. [23] confirm that this area of outdoor noise propagation and reduction still needs additional research.

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* To explain this 3 dB maximum noise level increase, the rule for combining sound levels by "decibel addition" must be understood. When two noise levels differ by a maximum of 1 dB, then their cumulative effect is found by adding 3 dB to the larger value.

TABLE 4

Reduction in Reflected Noise Level
(From Reference 1)

Noise Reduction Coefficient, NRC	Reflected Energy Reduced by this Amount
0.95	13 dBA
0.90	10 dBA
0.85	8 dBA
0.80	7 dBA
0.75	6 dBA
0.70	5 dBA
0.65	4.5 dBA
0.60	4 dBA
0.55	3.5 dBA
0.50	3 dBA

Author's Comment: The following are approximate NRC values for several different kinds of materials.

MATERIAL	NRC
Concrete, smooth finish	.02
Wood panel	.05
Normal weight aggregate block	.27
Light weight aggregate block	.45

CONCLUSIONS

With the general exception of the construction that has taken place in California, the use of highway noise barriers is still in the preliminary experimental stages.

The noise reducing levels can be theoretically predicted with the FHWA approved models of NCHRP #117 and TSC, assuming that the basic acoustic parameters of density, thickness, length, and effective barrier height are fulfilled.

The cost of constructing noise barriers is still dependent on the local highway design and the availability of adequate noise barrier material.

Further research is needed on outdoor noise absorptive materials and standardized barrier designs.

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