Sound-Absorption Treatments for Highway Noise Barriers

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Various aspects of the use of roadside barriers to reduce levels of traffic noise in nearby communities are discussed. These include the need for barriers on both sides of a highway, the resulting degradation of barrier performance, and the need to incorporate sound-absorbing facings into barrier designs. A general overview of sound-absorbing materials is given, and some common misconceptions about reducing highway noise are examined.

When a highway passes through a densely populated area, noise control is often required, and barriers are frequently the only practical means of noise control. If there are residential areas on both sides of a highway, two barriers may be necessary. When two vertical barriers are used, however, the noise-reducing capability of each barrier is usually compromised.

As Figure 1 shows, the sound that emanates from passing vehicles is reflected back and forth between the barriers. Eventually, the noise spills over the tops of the barriers and travels directly into residential areas. Much of the benefit provided by using one barrier is lost when a second barrier is added because the second barrier acts as a reflecting surface and causes multiple sound reflections between the two surfaces.

In 1975, the Federal Highway Administration (FHWA) sponsored a study of the effects of multiple sound reflections in walled highways (1). The study included an acoustical scale-model analysis of the effects of barriers on both sides of a highway. The study predicted the extent to which the noise-reducing capability of an individual barrier was degraded by the addition of a barrier on the opposite side of the highway. This noise reduction was evaluated in three different "receiver zones" (see Figure 2). In zone 1 a receiver could not see the far barrier, in zone 2 a receiver could see some of the far barrier but not the source, and in zone 3 a receiver could see the source.

Figure 3 shows examples of the performance of an individual barrier and the degradation that results in each of these receiver zones from the addition of a second (far) barrier (concrete or steel barriers are assumed in these examples). In zones 1 and 2, the loss in barrier attenuation was very significant: 5-7 dB. Note that in zone 3, where the single barrier did not break the line of sight from the source to the receiver, the single-barrier attenuation was 0 dB. In this case, however, sound amplification occurred because the far barrier reflected a significant amount of sound energy toward the receiver, sound that was originally propagating away from the receiver. In this instance, the amplification could be as much as 3 dB.

The performance of a barrier can also be compromised when the two barriers overlap—for example, when a ramp joins a highway. As Figure 4 shows, when a barrier associated with a ramp overlaps the main-line barrier, sound is reflected back and forth between the barrier walls on each side of the ramp. The sound energy then propagates directly into nearby residential areas. Recent work by Bolt Beranek and Newman, Inc., for the city of Baltimore, Maryland, has shown that, when this or similar barrier configurations exist, the effectiveness of otherwise very effective noise barriers (barriers that provide 10-15 dB of attenuation) may be significantly compromised (yielding less than 10 dB of attenuation) for some residences.

RESTORING BARRIER PERFORMANCE

An effective way to prevent the degradation of performance in a two-barrier system is to make the barriers sound absorbing. If most of the sound incident on a barrier is absorbed, the remaining reflections will no longer be significant. Therefore, if the barriers are efficiently sound absorbing, the far barrier will not compromise the performance of the near barrier, and the effectiveness of an absorptive two-barrier system will be as good for both sides of a highway as a single barrier is for one side of a highway.

USE OF SOUND-ABSORBING MATERIALS TO IMPROVE BARRIER PERFORMANCE

A sound-absorbing material absorbs sound by forcing air molecules to move in and around many tiny fibers or passages. As the air molecules are forced in directions other than a straight back-and-forth motion, they lose energy, and sound intensity or sound level decreases.

Some familiar objects that are made of materials that absorb sound are thick carpeting, stuffed furniture, and heavy draperies. Fabrics are soft and fibrous, characteristics that make them excellent sound absorbers.

How much sound a material absorbs (its sound-absorbing effectiveness) is usually rated by the material's absorption coefficient α. The absorption coefficient is defined as the ratio of the sound energy absorbed by a surface to the sound energy incident on that surface. α may take on all numerical values between 0 and 1. For a perfect absorber, $\alpha = 1.0$; for a perfect reflector, $\alpha = 0$. The absorption coefficient is specified at a certain frequency or over a range of frequencies. The absorption coefficient of a material is commonly specified in octave bands, from 63 to 8000 Hz. For example, a poured-concrete surface has an absorption coefficient of 0.02 in the 500-Hz octave band; virtually all of the sound in that octave band is reflected (2). On the other hand, for a 5-cm (2-in) thick glass fiber blanket spaced 2.5 cm (1 in) away from a solid backing, $\alpha = 0.90$ in the 500-Hz octave band; therefore, 90 percent of the incident sound energy in the 500-Hz octave band is absorbed and, as a result, the level of the reflected sound is 10 dB lower than the level of the incident sound (3).

Figure 5 shows the effect of increasing absorption on the noise-reducing capability of a two-barrier system for three receivers in zones 1 and 2. This effect is shown for the 500-Hz octave band, the predominant frequency region for truck noise. At a receiver height of 4.6 m (15 ft), the height of a typical second-story window, the attenuation increases to 11 dB when $\alpha = 0.8$ from only 5 dB when $\alpha = 0.05$. The single-barrier attenuation ($\alpha = 1.0$) is 12 dB (Figure 5).

Clearly, sound-absorption treatments will improve the performance of a two-barrier system. The effectiveness of barriers with gaps in them (Figure 4) can also be restored if the propagation corridor is properly treated with sound-absorbing material. However, for outdoor use, sound-absorbing materials must withstand

Figure 1. Multiple sound reflections in a two-barrier system.

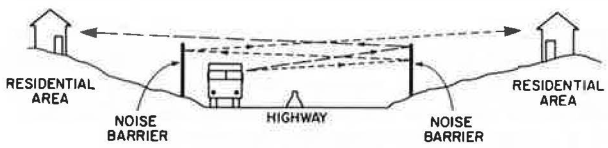


Figure 2. Receiver zones for a two-barrier system.

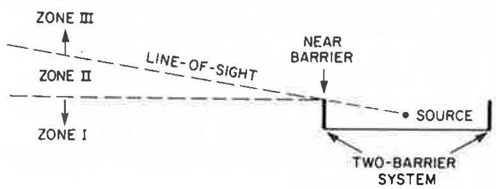


Figure 3. Degradation of sound attenuation by barrier.

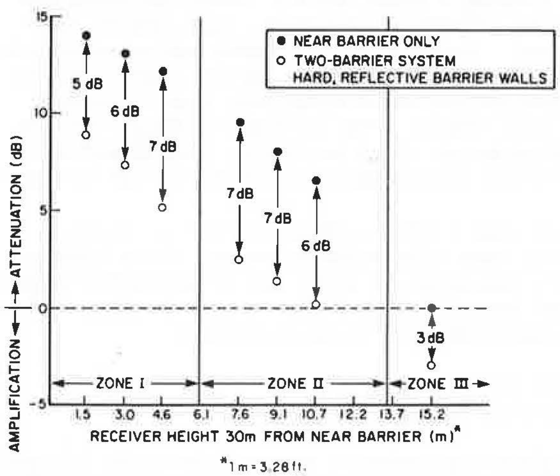
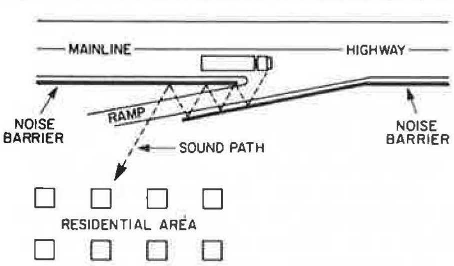


Figure 4. Sound path through overlapping barriers.

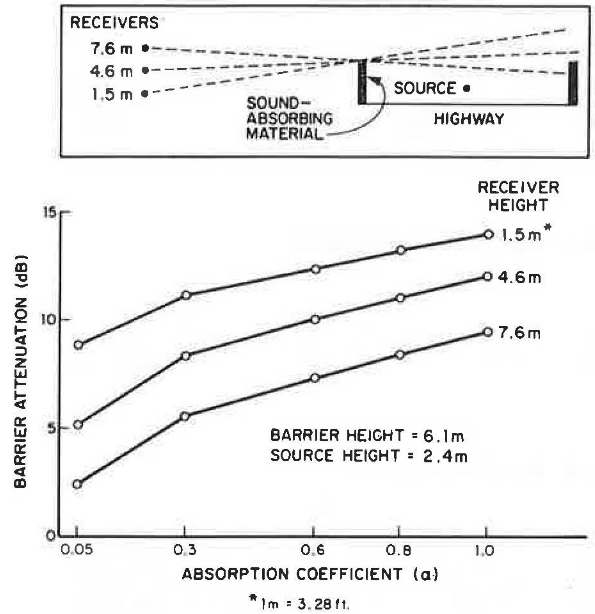


the effects of weather and dirt and must remain sound absorbing for many years. These are not trivial requirements.

SOUND-ABSORBING MATERIALS

A review of criteria for selecting sound-absorbing materials for use on highway noise barriers is given below. The characteristics of some selected materials and the reasons for rejecting other materials commonly believed to be effective for noise control are then discussed. A catalog of sound-absorbing materials and treatments for highway applications is given elsewhere (4).

Figure 5. Attenuation versus absorption coefficient for two-barrier system.



Criteria for Selecting Materials

Sound-absorbing materials should be selected to meet the following criteria (in order of importance):

1. Sound-absorbing capacity—Only materials that meet the sound-absorption criteria should be considered further. For highway barriers, it is necessary to install on the barrier surfaces sound-absorbing treatments that have absorption coefficients of 0.6 or higher. Absorption coefficients of at least 0.6 are necessary in the four most important octave bands for highway noise: 250, 500, 1000, and 2000 Hz.
2. Physical durability—Materials that meet the first criterion should have sufficient durability. In the highway environment, they will be exposed to sun, water, wind, salt, air contaminants, and temperature changes. To remain effective, they must be able to resist these elemental forces for many years.
3. Acoustical durability—Materials that have sufficient physical durability must also resist degradation of their sound-absorbing properties. Oil and dirt can clog the tiny passages between the fibers that make up sound-absorbing materials. Clogging effectively inhibits the motion of air molecules, which is the mechanism by which sound is absorbed. Since sound-absorbing barriers installed along highways have not been in use for long periods of time, little is known about the effects of highway oil and dirt on the acoustical durability of sound-absorbing materials.
4. Maintenance requirements—If the sound-absorbing capacity of a material decreases as a result of clogging, the effectiveness of the barrier will decrease. Cleaning the barrier face may restore its acoustical performance, but requirements for maintenance should be avoided if possible. In addition, the appearance of sound-absorbing barriers should not deteriorate over time, and their finishes should not require cleaning or painting.
5. Flame, fuel, and smoke ratings—Materials that meet all of the above requirements should have flame, fuel, and smoke ratings that are low enough that they can be used safely beside highways. We found only one class of materials that did not meet these criteria: Polymer

Figure 6. Covered highway.

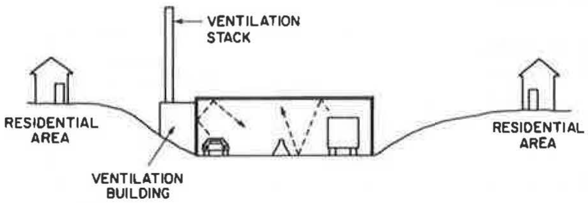


Figure 7. Earth berms as noise barriers.

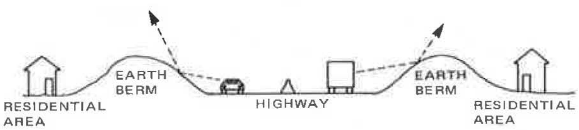
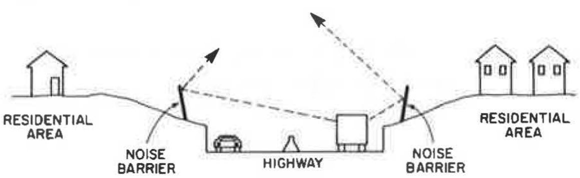


Figure 8. Sloped noise barriers.



foams produce cyanide or other highly toxic gases when burned and, although some foams are rated "self-extinguishing", they can continue to burn if fueled by other burning materials that might be present in an automotive fire. Most fabric materials, on the other hand, can be treated with flame retardants, if necessary, which would make their flame, fuel, and smoke ratings acceptable for placement near highways.

Specific Materials

Standard Effective Materials

Glass fiber, a standard material used by the construction industry, is one of the most useful and effective sound-absorbing materials for highway use. It is readily available, and its sound-absorbing properties have been extensively tested.

Several manufacturers have produced glass fiber in prepackaged assemblies for sound-absorbing panels or barriers. These integrated packages typically use two types of protective facings for the glass fiber: One is usually a perforated or expanded metal facing that protects the glass fiber from physical abuse, and the other uses a thin, waterproof plastic or mylar sheet that protects the fibers from moisture, dirt, air contaminants, and air sifting (fibers floating out into the air). Since these systems have high sound-absorption coefficients, they can be used effectively on highway noise barriers. Some of the systems have solid sheet-metal backs and so can be considered self-contained sound-absorbing barriers.

When a large system of sound-absorbing barriers is required, it may be prudent for the highway department or engineering firm to design its own sound-absorption treatment. One of the most efficient and cost-effective treatments is 5-cm (2-in) thick, low-density [approximately 24-kg/m^3 (1.5-lb/ft^3)] glass fiber batts mounted 10-20 cm (4-8 in) away from a hard, sound-reflecting barrier wall. Additional details are given elsewhere (4).

Thin Fabrics and Films

Laboratory tests have shown that some thin fabrics and films can be designed and fabricated to provide sufficient sound absorption for highway use. They must be mounted with an air space of 10-20 cm between their front face and any hard, sound-reflecting barrier wall.

Fiber density in fabrics and perforation density in films must be carefully controlled during production if the materials are to function properly. Fabrics or films specifically designed for outdoor absorptive treatments have not yet been manufactured because there has not been enough demand for them. In general, materials designed for other environments have been adapted to highway use. If the demand for sound-absorbing highway barriers increases, thin fabrics and films that maximize efficiency and minimize the quantity of material are likely to be produced.

Plantings

Dense evergreen trees, shrubs, vines, and grass are repeatedly considered as possible materials for noise abatement. They are often proposed both as sound barriers and as sound absorbers. In both cases, they exhibit such serious deficiencies that, apart from their use to meet other criteria for highway design (such as beautification and visual screening), they should not be considered to meet sound-attenuation criteria for highways.

Plants are simply unsuitable for use as sound-absorbing materials beside highways. To be effective, a plant's leaf structure would have to be similar in fineness and density to that of glass fiber. No plant with these characteristics has been identified.

ALTERNATIVES TO SOUND-ABSORBING MATERIALS

Sound-absorbing materials may be undesirable because of cost, maintenance requirements, or design constraints. There are a few alternatives to sound-absorbing materials that can be considered for particular situations.

Covered Highways

Excessive noise levels can be reduced dramatically by covering a highway (see Figure 6). However, other factors, such as cost and ventilation requirements, are usually primary considerations. A covered highway usually costs much more than even the most expensive noise-barrier design and, unless the tunnels are very short, they must be ventilated. Ventilation systems often require a high exhaust stack and additional structures to house the motors and fans. If they are not designed properly, ventilation systems can create their own noise problems.

Berms

Earth berms can be placed on both sides of a highway to act as noise barriers, as shown in Figure 7. Because of their shape, berms prevent sound from reflecting back and forth. They act effectively as single, independent barriers as long as no vertical walls are placed on top of them. However, berms have limited application as an alternative to absorptive barriers because their use requires a significant amount of right-of-way property. This alternative poses particularly difficult problems in urban areas, where space is limited.

Sloped Barriers

Figure 8 shows a configuration of sloped barriers that was recently tested in an acoustical scale-model study for the Harbor Tunnel Thruway in Baltimore (5-7). For this particular configuration—a depressed highway with residential areas on both sides—hard, reflective barriers sloping away from the highway at an angle of 10° from vertical were found to be as effective as an absorptive vertical two-barrier system.

Although very little information about the overall effectiveness of sloped barriers exists, sloped barriers should prove to be effective for configurations other than that of the Harbor Tunnel Thruway. Model studies will generally be required to determine optimal barrier locations and slopes, at least until enough data are collected to develop generalizations. For other configurations, sloped barriers may have to be higher than vertical absorptive barriers. Once the performance characteristics of sloped barriers are known, costs and installation limitations can be compared with those of absorptive two-barrier systems. Only then will the best applications for each approach be defined.

Sloped barriers, however, will not replace sound-absorbing materials in all applications. Where deep cuts require vertical walls or where space is limited, sound-absorption treatments will be the only effective means of eliminating the multiple reflections that degrade the performance of a two-barrier system.

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Noise Barriers Adjacent to I-95 in Philadelphia

Harvey S. Knauer

Pennsylvania's first major noise-barrier project, from inception to the later stages of construction, is described in detail. Construction of the barriers, which will total approximately 9300 m^2 (100 000 ft^2), was mandated by the terms of a 1975 consent decree signed by the Pennsylvania Department of Transportation, the Federal Highway Administration, the city of Philadelphia, and a coalition of local community groups. Final barrier locations, types, and sizes were determined only after extensive community participation. In several instances, tradeoffs were made between barrier height and the view of the historic Philadelphia waterfront. Barrier heights range from 2.4 to 8.2 m (8-27 ft). Cost varies from \$237 to \$912/m^2 (\$22-\$85/ft^2). When the barriers are completed, noise attenuation at ground-level observation points is expected to range from 6 to 15 dB(A). The project's history, funding problems and implications, techniques of barrier analysis, implications of barrier design and community participation, barrier costs, and observation of the overall process are discussed.

In eastern Pennsylvania, the Delaware Expressway (I-95) extends in a north-south direction generally paralleling the Delaware River for approximately 80 km (50 miles). Except for a 6.4-km (4-mile) section in the vicinity of Philadelphia International Airport that has been delayed by environmental problems, all of the expressway is open to traffic. A 4.8-km (3-mile) section in Philadelphia's Center City was completed in the spring of 1979, but its opening to traffic was delayed until late August 1979 by conditions of a consent decree signed in December 1975.

The 1975 consent decree was an agreement between the Pennsylvania Department of Transportation (DOT), the Federal Highway Administration (FHWA), the city of Philadelphia, and an organization called the Neighborhood Preservation Coalition (NPC). The NPC is an organization of approximately 20 constituent community groups in the vicinity of I-95 in the city of Philadelphia. The consent decree required, among other things, that noise barriers be constructed, where feasible, before the Center City portion of I-95 became operational (see Figure 1). It also required that barrier designs be acceptable to the NPC.

Before the signing of the consent decree, the Pennsylvania DOT had performed noise-monitoring and preliminary noise-prediction analyses. Under the terms of the consent decree, the DOT was required to obtain the services of an independent noise consultant to verify the preliminary analyses and to determine recommendations regarding feasible types and loca-