Can Noise Radiation From Highways Be Reduced by Design?

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This paper discusses a study to determine a desirable limit for external noise at residences nearest to a highway and the noise radiation characteristics of conventional highway designs. It presents some possible methods of reducing noise radiation by modifying these designs and some good and bad examples from practice.

The charts permit a reasonable prediction of future truck noise at various distances from a highway before the actual construction. All of the highway designs that are considered in this report are charted. The values are based on field measurements made adjacent to existing exemplary designs in normal operation at full highway vehicle speeds.

•THE problems arising from motor vehicle noise are a familiar topic in the press, and one does not have to be a noise expert to understand certain public reactions. Strong complaints are to be expected when the penetration of exterior noise to the interior of a home becomes severe enough to interfere with conversation, sleep, telephoning or the enjoyment of musical and TV programs. High exterior noise levels also prevent enjoyment of a patio or recreation yard.

Experience has shown that public reaction to the amount of exterior noise invading a backyard or impinging on a home can be anticipated (Fig. 1). The noise is ranked according to peak noise measured in decibels on the A scale of a sound level meter and is usually referred to, simply, as so many dBA. Evaluation of motor vehicle noise in terms of dBA has the approval of the International Standards Organization and the Acoustical Society of America. Recent findings by R. K. Hillquist confirm the merit of dBA over other single-number fast readout noise measurements (1).

The 70 dBA line (Fig. 1) is emphasized because it usually represents the maximum limit of exposure in a residential area before public complaint ensues. The complaints become stronger as the noise rises to higher numbers. A considerable variation in individual reaction is perfectly normal. Few complaints are received in industrial or commercial areas.

Perhaps the safest statement that can be made about the highway noise problem is that noise radiation from vehicles and, in turn, from the highway can be better controlled than it is now. Figure 2 shows

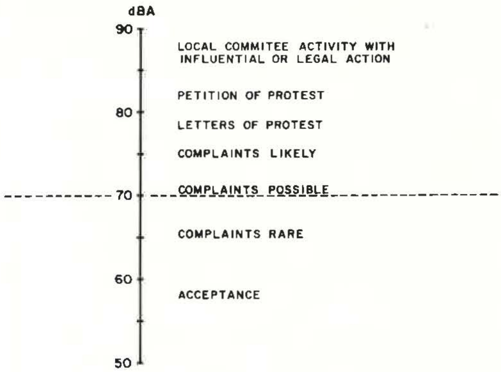

Figure 1. Trend of public reaction to peak noise near residences.

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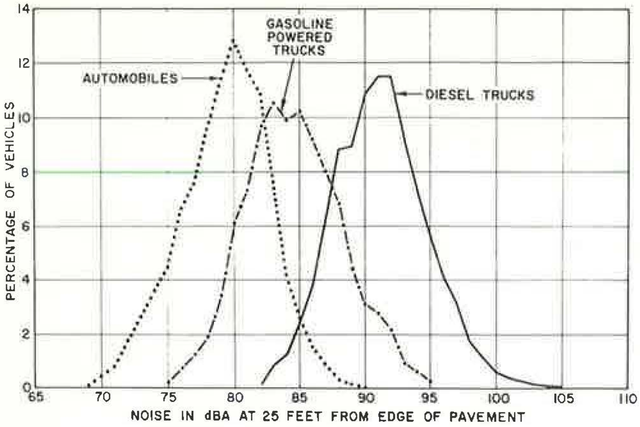

Figure 2. Measured noise distribution curves of highway vehicles.

that the major source of highway noise peaks is the diesel truck; therefore, the noise from diesel trucks will be used as the standard reference throughout this report.

In many well-planned residential areas the houses are often arranged with the bedrooms toward the rear to provide protection against the noise radiated from local vehicles. Local traffic often drops to nearly zero during the sleeping hours. The ambient noise may drop to levels of around 30 to 40 dBA when no vehicles are present.

If a highway penetrates this type of environment, a considerable change takes place. The highway traffic noise, more frequently than not, radiates toward the bedroom windows of the nearest exposed dwellings. The peak noise levels developed outside of these residences will vary with distance (Fig. 3). The figure of 70 dBA has a definite significance—it relates fairly well to the noise generated by local automobiles that may pass on the nearest city street during the night. Most people can adapt to this amount of external noise but would prefer a much lower figure if given a choice. Vern O. Knudsen (2) has suggested an acceptable maximum noise range of 35 to 45 dBA for the interior of apartments and houses. An exterior noise of 70 dBA can usually be reduced to 45 dBA, internally, by shutting the windows facing the source. Some people will object to this requirement, but experience shows that Dr. Knudsen's 45 dBA figure is well chosen as a maximum and that exterior noises in excess of 70 dBA will stimulate many complaints by raising the internal noise above 45 dBA. (If the nearest windows are partly open, an exterior noise maximum of less than 60 dBA is desirable.)

The most effective method for controlling airborne noise usually involves four steps:

1. Quieten the source (design-muffle-shield).
2. Spoil the path (interpose a dense, nonpermeable barrier).
3. Protect the receiver (obstruct or enclose).
4. Absorb the remainder (line the enclosure).

Unfortunately, the authority for exercising control over all of these steps does not rest with the highway engineer. Nevertheless, a beneficial range of control is available because each basic highway design has its own peculiar noise radiation characteristic. These inherent differences between various designs can affect the noise path (step 2) to a degree that may be slight or about 3 dBA; significant or about 6 dBA; or dramatic, say 10 dBA or more.

Almost equally important is the fact that certain design modifications offer an opportunity to reduce the noise even further. The degree of reduction that modifications can

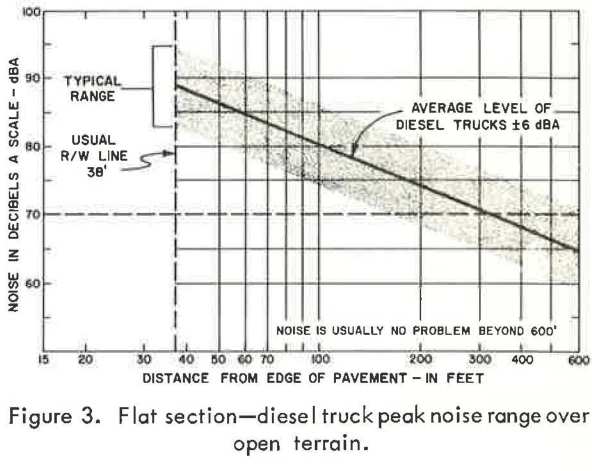

Figure 3. Flat section—diesel truck peak noise range over open terrain.

achieve may sometimes be just as great as already noted between different unmodified basic designs; namely, as much as 10 dBA or more. To avoid being overly optimistic, it should be said that not all modifications and variations are good ones. On the contrary, there are some variations that can destroy the noise shielding properties of an inherently quiet design in a given topography. There are others that make very little difference at all—except in the imagination.

UNMODIFIED HIGHWAY DESIGNS

The noise radiation characteristic of each type of highway presented is based on field measurements across open adjacent terrain. This represents the worst condition where no intervening buildings inhibit the soundpath and the highway profile becomes the dominating factor at a given distance from a vertical reference line at the edge of the pavement.

Flat Sections at Grade—Reference Condition

In Example A_1 (Fig. 4), the noise drop is 6 dBA for each doubling of distance as shown in Figure 3. The distances in Figure 4 are not quite double because the toe or top of most urban freeway fill slopes and cut slopes are at least 60 ft from the edge of the pavement. The next point shown is 100 ft from the edge of the pavement because it is an easily remembered number. All of the other designs are rated in terms of their relative noise advantage over A_1. In every case the microphone of the sound level meter is 5 to 6 ft above the ground. This is about ear height or about the same as window height in many single level residences.

Elevated Highways on Structure or Narrow Shouldered Fill

Example B_1 shows a slight advantage (3 dBA over A_1) for highways that are elevated on a structure or a narrow shouldered fill. The advantage is not very important for adjacent land areas but does become important underneath a structure with a solid deck. This should encourage the growing trend toward commercial exploitation of the space beneath a structure where the measured noise seldom exceeds 70 dBA from overhead traffic. The noise from adjacent city streets will usually exceed that from the highway.

Elevated Highways on Broad Shouldered Fill

Example C_1 shows a significant advantage (6 dBA over A_1) for highways that are elevated on a broad shouldered fill. This improves rapidly where the ramps widen the shoulder and begin to shield the traffic from view near the bottom of the slope. A 12 dBA advantage is possible where the tallest trucks are 90 percent hidden. A 15 dBA advantage is common where the tallest trucks are completely hidden.

Depressed Highways

Example D_1 shows a dramatic advantage (11 dBA over A_1) for highways that are depressed 20 ft below the adjacent land, but only at distances where the vehicles are screened from view. The advantage diminishes rapidly as you approach the highway and the more remote vehicles become visible. The advantage over A_1 becomes zero near the crest of the slope where all shielding is lost.

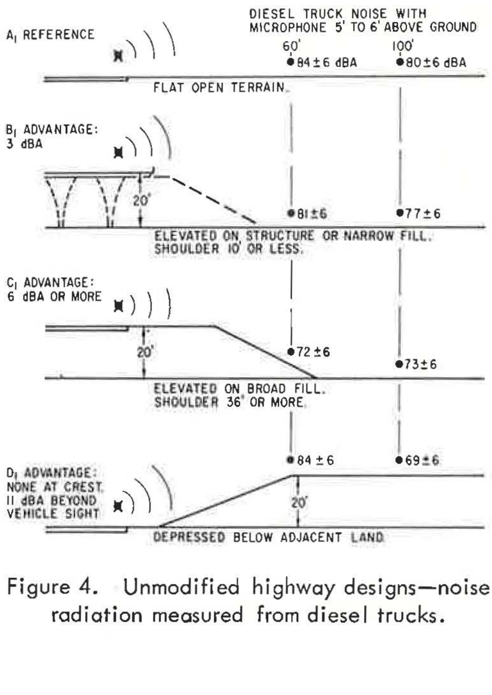

Figure 4. Unmodified highway designs—noise radiation measured from diesel trucks.

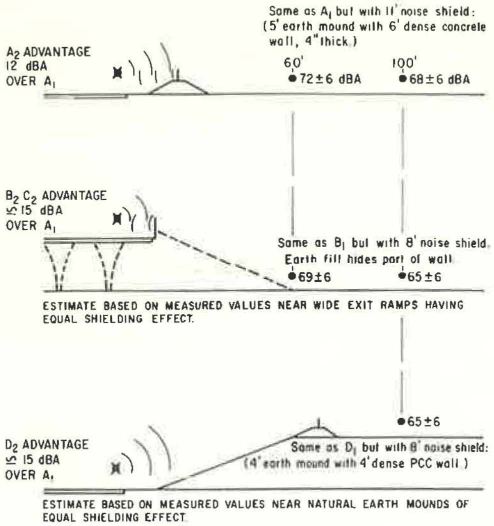

Figure 5. Modified highway designs for better noise reduction.

The preceding unmodified highway designs cover the most frequent conditions found near highways of conventional design. The major exceptions are those which might logically be anticipated. Tall buildings, with a direct view of the traffic, will have a direct range noise exposure about equal to that at the same distance from highway design A_1. The same will be true for direct line of sight positions on adjacent elevated lands or slopes. There is not much one can do to shield the highway where the adjacent land rises rapidly and permits a direct view of the vehicles over the top of any sound shield of reasonable height. This is simple geometry for either optics or acoustics. Favorable conditions exist where the adjacent land is fairly level or slopes downward away from the highway. The basic requirement for a sound shield or barrier is that it must block the view of the noise source (unless it is made of thick clear glass). A secondary requirement is that all of the remaining refractive or reflective soundpaths be rather poor ones, i.e., with high losses and low efficiency.

MODIFIED HIGHWAY DESIGNS FOR BETTER NOISE REDUCTION

Modifications can make a dramatic contribution to further noise reduction. The changes are great enough to be appreciated by either an untrained human observer or a sound level meter.

Shielding a Flat Section at Grade

The first modification involves adding a noise shield to highway design A_1 so that it becomes A_2 (Fig. 5). The advantage is 12 dBA quieter than A_1. A human observer would interpret this as a drop to about 40 percent of the original noise condition. This figure is based on actual measurements obtained in schoolyards where 11-ft high concrete walls served as the noise shield. The same amount of protection can also be found where natural earth mounds offer an equal amount of optical shielding. Although as effective acoustically, the use of an 11-ft high earth mound would require more footing width than is usually available along the right-of-way; and an 11-ft high wall might raise objections about appearances; but the combination of a 5-ft earth mound topped by a 6-ft wall can be visually pleasing as well as functional (Fig. 6).

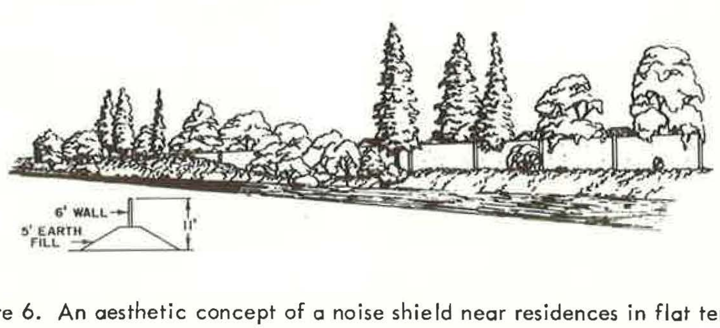

Figure 6. An aesthetic concept of a noise shield near residences in flat terrain.

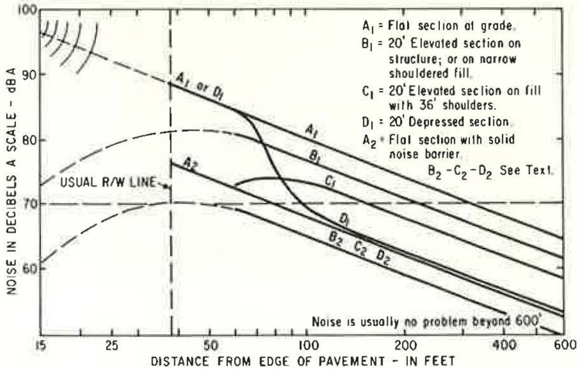

Figure 7. Noise comparison chart for different highway designs—based on average truck noise with ±6 dBA spread; adjacent land flat and unobstructed; microphone 5 ft above ground.

Shielding an Elevated Highway

The center example, B_2C_2 (Fig. 5), illustrates a method of adding an 8-ft noise shield to a highway that is elevated on either an earth fill or a structure, B_1 or C_1. It is easier to screen the appearance of a noise shield at the crest of a fill, with some earth overlap and plantings, than it is to camouflage it at the side of a structure. Architectural ingenuity is needed. The noise protection may be worth the trouble where sensitive adjacent dwellings lie below horizontal incidence and the vehicles can be completely obscured. Under these conditions the noise advantage over A_1 is about 15 dBA. This is equal to reducing the noise to 25 percent of highway A_1 in terms of human hearing response. At more remote distances the advantage declines slightly but so does the need.

Shielding a Depressed Highway

The lower example, D_2 (Fig. 5), shows the addition of an 8-ft noise shield at the crest of the slope near a depressed highway. This is a most effective method for improving the noise protection to nearby dwellings that would otherwise have a direct optical and acoustical exposure to the vehicles. If the addition of the noise shield results in blocking the line of sight noise path, a 15 dBA advantage is possible over highway A_1. Of course, the more remote dwellings that were already optically shielded will not experience the same amount of change, but even these will obtain an improvement of about 4 dBA. In the latter instances, the advantage over A_1 will change from 11 dBA as shown on D_1 to 15 dBA as shown on D_2 at the more remote distances.

Figure 7 shows a noise comparison chart which summarizes all of the highway conditions covered.

SOME PROPERTIES OF MATERIALS FOR NOISE SHIELDS

Good sound shields must have reasonable mass and be impervious to air flow. In other words, they must neigher vibrate easily nor leak air through themselves. Dense concrete slabs or blocks with all cracks fully mortared are a good example. Earth mounds are even better because they can both block and absorb sound energy. Porous cinder blocks or expanded shale blocks offer a distinct advantage if given a final stucco coating on only one side after the installation. The side to be coated must face away from the highway. The side toward the vehicles should remain porous. With this technique the porous side acts as a sound absorber and the coated side improves the transmission loss or shielding effect (3).

Dense concrete materials are indicated in all sketches showing noise shields along highways, because of the superior durability of dense concrete in freezing and thawing environments. In other less demanding climates, the advantage of expanded shale materials may be exploited, especially when precast slabs are used. It may be desirable to face one side of the slabs with a thin layer of dense concrete or mortar.

SOME EXAMPLES

Figure 8 is an example of how the good shielding properties of a wide shoulder on a fill can be destroyed by the addition of an overhead structure that curves over the freeway and acts as a gigantic reflector as it turns and parallels the highway and the adjacent

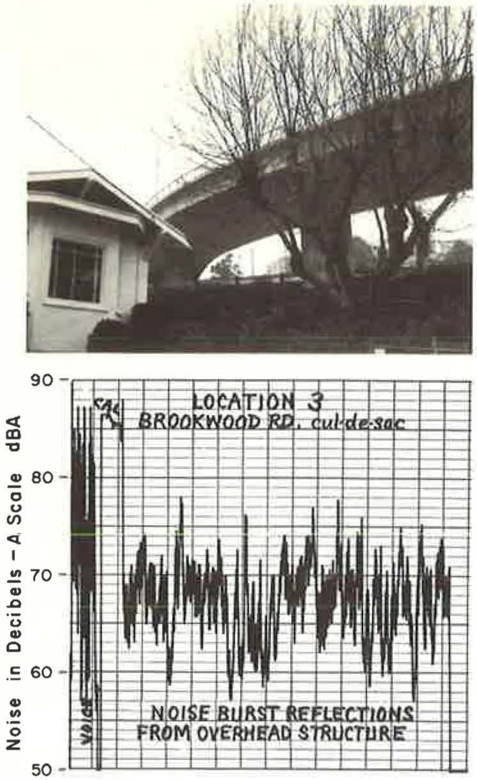

Figure 8. Short sample of noise recording; long-term measurements vary from 58 to 80 dBA.

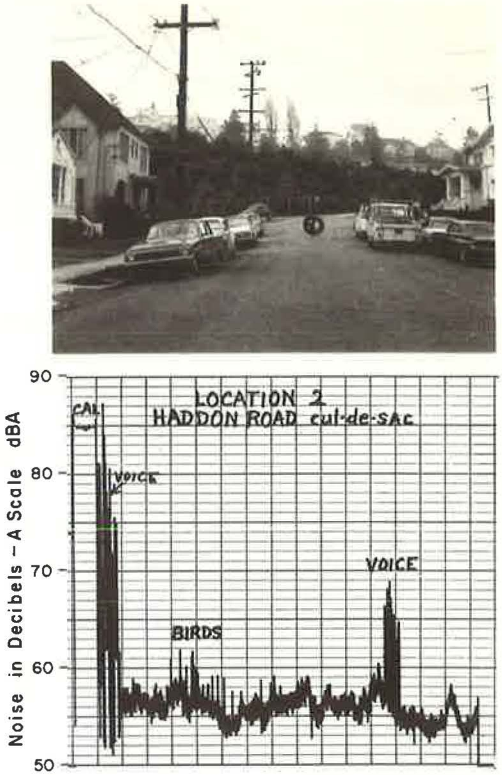

Figure 9. Short sample of noise recording; long-term measurements vary from 52 to 59 dBA.

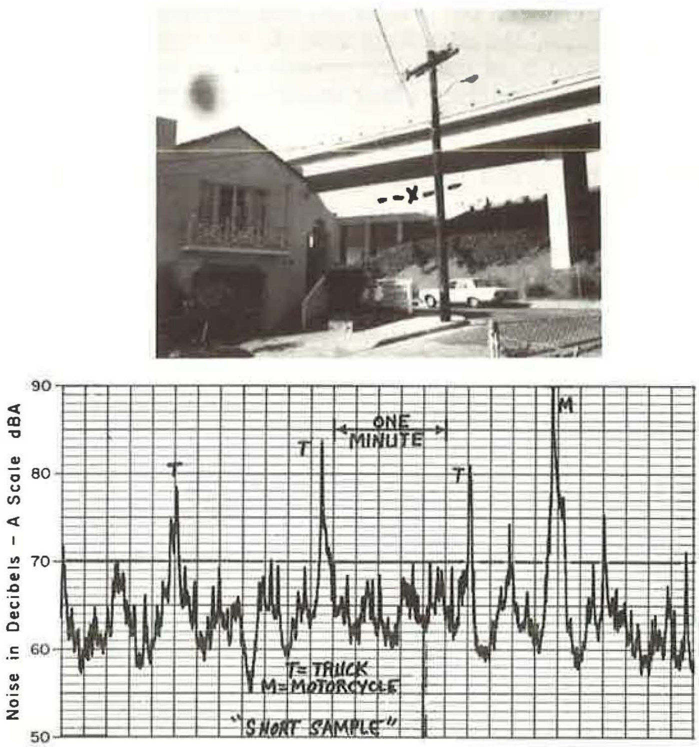

Figure 10. Noise peaks range from 70 to 90 dBA.

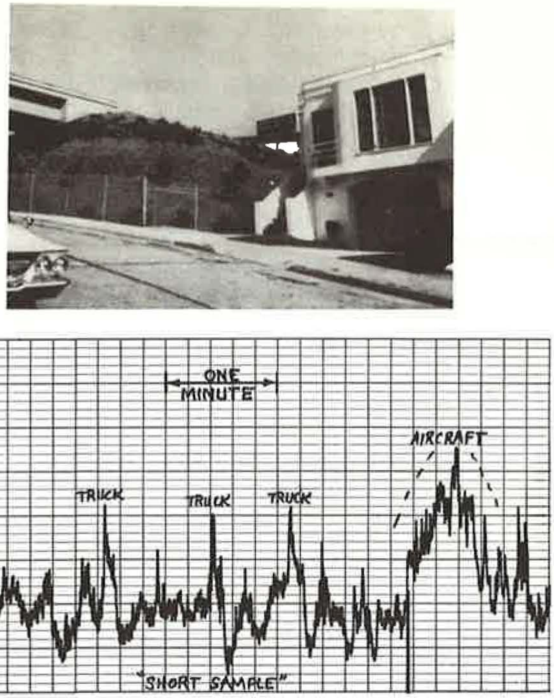

Figure 11. Noise peaks rarely go above 71 dBA except from aircraft; the earth fill acts as a noise barrier for traffic.

residences. The noise bursts come from vehicles out of sight, beyond and below the structure. The bottom side of the structure is in a perfect position to reflect the noise bursts down to the residences. The vehicles on top of the structure are well hidden and are virtually inaudible in comparison with the burst noise from invisible highway vehicles below the structure.

Figure 9 shows the dramatic change after the same structure descends and joins the exit ramp shoulder. The noise bursts disappear and the wide shoulder shields the traffic noise so well that the loudest noise on the chart is from chirping birds as shown on the recording. The peak marked "VOICE" was a comment by the recordist. Figures 8 and 9 show adjacent cul-de-sacs about 300 ft apart.

Figure 10 shows a residence exposed to very high noise peaks. The vehicles on top of the elevated bridge structure are not the cause. Highway trucks pass in the visible space (between the elevated bridge structure and the fill) at --X--. The direct noise bursts from the trucks are enhanced by reflections from the bottom face of the elevated bridge structure. Other noise peaks come from vehicles entering a tunnel colonnade under the highway fill, which can be seen slightly left of center. This tunnel approach is backed by a concrete retaining wall alongside of the highway. Thus, the entire combination is a multiple source of direct noise bursts, exalted by reflections and accompanied by reverberations from the tunnel.

Figure 11 shows a large earth fill just across the street from the residence in Figure 10. The house adjacent to this fill is very well shielded from traffic noise. This can be readily seen by a comparison of the two noise recordings.

The audible change is almost startling when a person walks from the north side of the shielded house in Figure 11 to the north side of the exposed house in Figure 10.

PLANTINGS

Sooner or later the question of planting is brought up during any discussion of noise radiation from highways. This topic should be laid to rest. The simple truth is that plantings possess none of the physical properties required of a good sound shield. They are porous to air flow, vibrate easily, and lack density. Their permeability to the flow of airborne sound is so great that virtually no acoustical benefit is obtained from planting within the right-of-way depth that is normally available. Their real merit is to improve appearances, and there is some "psychological shielding" that tends to favor public acceptance. Noise benefits are mostly folklore (4, 5, 6, 7, 8).

REDUCING NOISE AT THE SOURCE

Noise reduction at the source is an axiom in noise control. In the case of highways, the vehicles are beyond the control of the highway engineer. Many large diesel electric locomotives with two 2000-hp engines often radiate less noise than the 200 to 300-hp diesel trucks found on the highway. Diesel trucks can be made quieter (10). This would be a great step toward improvement, but it would not solve the entire problem, and it would not remove the need for quieter highway designs. Automobiles at full highway speeds radiate about 10 dBA less noise than the trucks, but some of the noisiest automobiles are more of a problem than the quietest of the trucks (Fig. 2). Noise control is usually needed along the highway wherever the external noise peaks exceed 70 dBA at the nearest dwellings in residential areas. Figure 7 compares various highway designs against the average of noise peaks ±6 dBA; therefore, only designs A_2, B_2, C_2, and D_2 are marginally acceptable to residences at less than 100 ft. D_1 is acceptable beyond 150 ft, C_1 at 250 ft, B_1 at 350 ft, and A_1 beyond 500 ft.

SUMMARY

The examples and conclusions in this report are based on several hundred noise measurement studies that were made at exemplary locations along highways in normal operation.

All of the measurements were obtained with General Radio sound level meters and graphic level recorders. Acoustical calibration was performed before every test run and repeated at intervals not exceeding one hour.

Highway design can include better noise control in the total engineering package. If this is ignored, the growing public awareness may bring increasing opposition to new highways in residential areas.

ACKNOWLEDGMENT

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