Abatement of Highway Noise with Special Reference to Roadside Design

First Report of Special Task Committee on Roadside Design to Reduce Traffic Noise, Dust, and Fumes (1953 Study)

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This report deals with the noise which emanates from the highway to the surrounding area, particularly to abutting property, as well as with what may be done by the highway engineer to make this noise less objectionable to roadside dwellers.

The report has intentionally been limited in scope to the recognition that there is need for abatement of highway noise; to a few units of measurement; information as to what is known; the citing of a few examples; and recommendations for scientific research in this field. The list of references is perhaps the most important contribution since it affords the reader the opportunity to explore for himself the best information available at this writing.

Specialized techniques for measuring noise are beyond the scope of this report. These are discussed in detail in references (5, 6, 7, 8, 16).

IN the United States, we have more motor vehicles rolling over our highways than we have telephones. Late in the fall of 1953, the 50 millionth telephone was presented to President Eisenhower with appropriate ceremony in the White House. At that same time, however, there were more than 54 million motor vehicles registered in this country. Significant also is the fact that the proportion of trucks is continually increasing. With this increase in highway traffic is a corresponding increase in highway noise. Finch and Andrews, in their March, 1951, research report on "Highway Noise and Its Measurements," point out that the increase in number and weight of vehicles has multiplied the number of complaints of excessive noise. More and more people are coming to the conclusion that: "There ought to be a law against excessive highway noise."(1)

As highway traffic increases, the need for roads with greater capacity increases. In metropolitan areas particularly, plans are being made for extensive developments of controlled-access highways, expressways, and parkways. In Los Angeles County, California, alone, more than 600 miles of these facilities have been planned (2).

Noise — A Factor in Highway Planning and Design

These facilities, particularly the controlled-access type, accommodate enormous volumes of traffic. The noise generated by such traffic volume is rapidly becoming a serious annoyance. Reduction of highway noise, therefore, presents an engineering problem in which automotive engineers and highway planners and designers are vitally concerned. Evaluation of this noise factor and the development of practical methods for its abatement are especially needed.

The following approach in dealing with highway noise is quoted from Technical Bulletin Series No. 1, Western Highway Institute (3):

"The problem of automotive noise can be approached from several angles. First is the design and improvement of vehicles. Mufflers can be designed and constructed which will substantially reduce exhaust noise. The possibility of reducing other vehicle noises, gear howl, tire squeal, etc., is constantly being studied. Second is the operation of vehicles. Truck routes can be made to bypass congested and residential areas by adequate planning. Unnecessary stops can be eliminated by proper planning and design of traffic signals and stop signs. Third is the design of the highway. Acquisition of adequate right-of-way widths and proper control of the right-of-way will keep buildings a greater distance from the traffic lanes and thereby reduce the effect of noise.

TABLE 1
CITY NOISES

(Motor-Vehicle, Industrial-Area, and Residential-Area Noise)
Selected for Analysis by Special Task Committee

Study of Noise Abatement on Highways with Particular Reference to Roadside Design

Source of Noise		Relative Loudness in Sones Calculated from Octave Band Levels		
Type of motor vehicle or area	Distance from source	Maximum loudness (approx.) sones	Range for 50 percent of cases measured (approx.) sones	Minimum loudness (approx.) sones
1. Heavy trucks	20 ft.	210-190	190-100	100-80
2. Motor coaches (accelerating)	20 ft.	170-120	120-70	70-65
3. Light trucks	20 ft.	80-75	75-40	40-30
4. Automobiles	20 ft.	60-55	55-25	25-15
5. Background traffic noise	25-100 ft.	75-35	35-15	15-5
6. Industrial area noise		65-25	25-10	10-5
7. Residential area noise		45-10[a]	10-5	5-0[b]
Suggested limiting figure		35	Below 25 not objectionable	

[a] Due mainly to traffic or industry
[b] At night

Noise of Heavy Trucks (1)
Noise of 1 is approximately 1 1/2 times noise of 2. (Motor coaches accelerating)
Noise of 1 is approximately 2 1/2 times noise of 3. (Light trucks)
Noise of 1 is approximately 4 times noise of 4. (Automobiles)
Noise of 1 is approximately 4-9 times as loud as 5. (Background traffic noise)
Noise of Automobiles (4)
Noise of 4 is but 1 to 2 times as loud as 5. (Background traffic noise)

NOTE: Adapted from chart of City Noises, Chicago Noise Survey, "Measuring Noise in our Cities" by Dr. H. C. Hardy, Armour Research Foundation, reprinted in Urban Land, Vol. 11, No. 10, pp. 3-5 (1952); and from chart reproduced in Highway Research Abstracts, Vol. 23, No. 2, p. 3 (1953).

Fourth is setting buildings back from traffic lanes and the planting of trees and shrubbery for screening."

The reduction of noise in motor vehicles is an automotive engineering problem on which cooperative research is now being done by several groups (1, 1-A, 3, 4, 16). The greater the reduction of traffic noise at the source, the less noise there will be for the highway engineer to abate.

The Human Element

Highway noise is not a problem until there is a listener. The solution should have two primary objectives: first, to reduce noise to a level acceptable to the listener; and second, to determine a specific noise level which can be measured and controlled (3, 14, 15, 16).

Noise may be defined as "unwanted sound." First, we must distinguish between objective sound and the "sensation" it produces by means of the human ear. Physically, a sound is a pressure wave in an elastic medium. It does not travel through a vacuum.

Physiologically, a sound is an auditory sensation produced through the ear by sound waves. Psychologically, a sound may be less annoying when the source is not visible to the listener (10, 11).

There are several psychological factors involved. One of these is the tendency of the listener to ignore background noises considered normal. Complaints occur when a few noises are much louder than the background noise, or when the noise interferes with sleep, conversation, or other activities (3, 4). Likewise, the number of people affected increases with loudness. Where there is a uniform distribution of population adjacent to a highway, if a noise is doubled, it will be heard by four times as many people (1, 8). Table 1 indicates that reducing noise from heavy trucks is the primary problem.

Noise — From Traffic on Highways

A complete report on the measurement of highway noise was made in 1952 by the Armour Research Foundation of Illinois Institute of Technology (8). The Cook County Highway Department requested this study on the Edens Expressway in Chicago, Ill., because of numerous complaints by the area residents (Figure 9). Of most interest is the comparison of heavy-truck noise to passenger-car noise, and to an acceptable background noise. At a distance of 300 ft., passenger cars at 55 mph. are approximately as loud as an acceptable background noise for the area. Accelerating trucks were reported four times as loud as passenger cars at 55 mph. Trucks at 50 mph., not accelerating, were three times as loud as passenger cars at 55 mph. Tests of truck "pullaway" noise indicate a loudness ratio of two to one for a noisy and a quiet "pullaway."

Trucks operating at wide-open throttle at average to high speeds when passing a vehicle or climbing a grade are more noisy than when on a level highway at constant speed. Trucks on the expressway generally are less noisy than on arterial streets or highways with stoplights or stop signs. The noise of accelerating from the stop position is greater than that of the running condition by 30 to 50 percent in loudness. When measured only 30 ft. from the vehicle, the noise from an accelerating heavy truck is comparable to that of a noisy factory area. At 300 ft., it is one-sixth as loud, and at 1,000 ft. the truck noise is one-seventeenth as loud. Generally, it was found that the loudness at 1,000 ft. is one-third of that at 300 ft. This loudness at 1,000 ft. is about the average for residential-area background noise in many suburban localities. At a distance of less than 1,000 ft., noise of an average truck is heard above the background noise of a quiet residential area.

Various Methods for Traffic-Noise Abatement

A number of examples have been reported on various methods which have been more or less successful in abating traffic noise. Dr. H. C. Hardy of the Armour Research Foundation reports (9):

"An earthen bank parallel to a railroad track can help in screening train noise. In Chicago, the Illinois Central, as it runs along the lakefront, is provided with a wall along the side toward the city. On top of the wall there is planting. In the parks, except for an occasional train whistle, the noise of the railroad cannot be heard against the high level of other traffic noises in the immediate area." (See Figure 6.)

Another example shows how a pleasing background noise will often mask unwanted traffic noise. A property owner abutting the Merritt Parkway in Connecticut was bothered by traffic noise, especially at night. After installing a fountain, the traffic noise no longer seemed so objectionable because the splashing of water in the fountain masked the noise from the parkway sufficiently so that it was no longer bothersome. Traffic noise which would be unacceptable in a quiet residential neighborhood would be unnoticed in an industrial or other noisy area where the background noise masks the noise generated by traffic. The masking effect of background noise should be kept in mind in comparing alternate locations for new highways.

It has been informally reported to the Highway Research Board that several methods of muffling traffic noise have been found to furnish some relief. These methods include dense evergreen plantings, solid fences, walls, and in one instance a narrow earthen embankment. No measurements have been made on the reduction of traffic noise by any of these methods, but after property owners had made such installations, there were no further complaints.

Texas cited an experience where noise from a depressed expressway faded rapidly as the distance from the roadway increased. At a distance of 100 ft., measured either from the retaining wall or from the upper edge of the sloped cut-bank, traffic noise was almost inaudible. There were no buildings higher than two stories along this depressed highway. No information was available on the noise at a height of four stories and more above ground. Reports have been made from other sources, however, that traffic noise is objectionable at a height of four stories and more (Figures 7 and 8).

In Los Angeles, a depressed highway was constructed through a motion-picture studio lot for approximately 1,000 ft. in a cut about 20 ft. below the general ground level, with 3 : 1 and 2 : 1 cut slopes respectively, planted to trees, shrubs, and ground cover. Since then, the studio has made no complaints on objectionable highway noise.

In one of the western states, the highway department employed consulting accoustical experts to study the possibilities of noise abatement on an expressway in a critical area. It was estimated that noise would be reduced at least 8 db[1] by the installation of 6-ft. earthen or concrete side walls, on which would be planted a dense hedge at least 4 ft. high. The inner surfaces of these walls would be covered with vines at least 6 in. thick further to reduce the noise by 4 or 5 db. Thus an overall noise reduction of at least 12 db would be provided to insure against any increase in highway noise resulting from anticipated automobile traffic.

Planting of Highway Borders to Reduce Highway Noise to Abutters

Most of the examples of traffic-noise abatement just described were either depressed sections of highway, or were walls or earthen embankments. In only a very exceptional case, however, would a highway designer deliberately depress a highway or even build a wall or an embankment for the single purpose of reducing traffic noise. In humid regions, by far the most economical method is the installation of buffer plantings, except possibly where right-of-way costs are prohibitive.

As far as known, no scientific tests have been made to record the amount of noise reduction by buffer plantings. Acoustical experts do not agree among themselves. Many isolated cases have been reported, however, where plantings have effectively reduced traffic noise. Whether or not such plantings materially decrease traffic noise, there is general agreement that they do have a psychological effect on roadside dwellers. Where traffic is screened from sight, the sense of privacy is increased and traffic noise seems

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[1] Explanation of the unit "db" (decibel): A noise of 1 db is just barely audible. It will be noted that the noises of the average residence environment may be about 45 db. When noises of about 50 db. are measured, a noise which average persons would rate twice as loud would represent an increase of 9 to 10 or would register about 60. The important point is that a reduction of 10 db. out of 100, let us say, is not just a 10 percent reduction; it is a very significant and worthwhile reduction in its effect on a "listener."

"Anyone who has stood beside a railroad track and listened to the noise from a train as it enters a "cut" where there is an embankment between the listener and the train must have noticed the low-frequency components of the sound are bent over and around the barrier, the higher frequency components are not; for the latter, the barrier "casts a shadow" and the overall noise at the position of the listener is reduced. Thus an earth embankment or a masonry garden wall often can be used to reduce the noise that impinges on a building and aid in the establishment of quiet conditions within the building without resorting to costly measures of sound insulation. It may reduce the (noise) level by as much as 5 db.

"If the surface of the barrier facing the source of noise is absorptive, such as a grassy turf, dense vines, other planting, or even leaf mold or peat moss, the overall noise reduction may amount to as much as 7 or 10 db. Hedges or trees with dense foliage act as sound absorbers and reflectors, and their effectiveness increases with the extent (thickness, height, and density) of growth."

From: Acoustical Designing in Architecture - p. 223 (Knudsen and Harris).

less objectionable. From the isolated cases mentioned, state engineers reported from personal observation that there was a satisfactory reduction in noise at adjacent residences due to planting (12, 13).

To be effective, buffer plantings should never be installed as an after-thought. The need for such plantings should be foreseen if possible at the time of right-of-way purchase so that adequate space may be provided along highway borders. Assuming that buffer plantings will be limited to major highways where traffic is heaviest, and that AASHO standards are followed, a width of 60 ft. of right-of-way on each side of the pavement is desirable to provide for shoulder, gutter, and buffer-planting space. This general statement applies to all types and widths of major highways and to the three general types of cross-section described later (Figures 1, 2, 3, 4).

Depressed Type of Highway Cross Section

Shoulder width (for emergency use)	10 ft.[a]
Gutter width (for adequate drainage)	13 ft.[a]
Planting set-back (for drainage clearance)	2 ft.[a]
Planting clearance from edge of pavement	25 ft.
Buffer-planting width	35 ft.[b]
Total (One side only)	60 ft.

[a] See "Detail sketch of gutter for two types of cross section" (Figure 5).
[b] A well-rounded 2 : 1 cut slope 15 ft. high would require all of this 35-ft. width - (2 x 15 + 5 = 35).

Raised Type of Highway Cross Section

Shoulder width (for emergency use)	10 ft.
Allowance for guard rail	2 ft.
Graded width	12 ft.
Planting set-back (from slope intersection)	3 ft.
Planting clearance from edge of pavement	15 ft.
Buffer-planting width	45 ft.[a]
Total (One side only)	60 ft.

[a] A well-rounded 2 : 1 fill slope 20 ft. high would require all of this 45-ft. width - (2 x 20 + 5 = 45).

Level Type of Highway Cross Section

Shoulder width (for emergency use)	10 ft.[a]
Gutter width	15 ft.[a]
Planting clearance from edge of pavement	25 ft.
Buffer-planting width	35 ft.
Total (One side only)	60 ft.

[a] See "Detail sketch of gutter for two types of cross section" (Figure 5).

The three types of cross section described above are for guidance only. They are subject to modification to meet the particular conditions for each project. It should be noted that where deep cuts and high fills occur, right-of-way requirements for grading may exceed the suggested total 60-ft. width.

Buffer Planting in Relation to Width of Right-of-Way

Buffer planting width may be generally classified as:

Narrow (Short distances only)	15 - 25 ft.
Basic (Recommended minimum)	25 - 35 ft.
Wide (Desirable for effective results)	35 - 45 ft.

The wider the buffer planting within the limits described above, the greater are the possibilities for obtaining effective and pleasing results. On the other hand, these possibilities lessen as the planting width lessens. A narrow 15 to 20-ft. width of planting appears hedge-like and is less effective. For these reasons, such narrow widths should extend for short distances only.

Selection and Use of Plant Material

A careful analysis of local conditions and requirements is necessary in the selection of plant material for use in buffer planting. As a rule, deciduous trees and shrubs are more suitable than evergreens in most regions of the United States that are favorable to planting. They cost less, are less formal in character, and are more tolerant of unfavorable city conditions. In addition, more species are suitable for roadside use. On the other hand, evergreens have the advantage of being effective in winter as well as in summer. A mixed planting with deciduous trees and shrubs predominating provides greatest variety and interest throughout the year. For all-year effectiveness, a narrow planting requires a greater proportion of evergreens than does a wide planting. The proportion of evergreens may be reduced, however, if a "buffer" is needed only in warm weather when windows are open and people are out of doors.

Trees and shrubs used in buffer planting should be selected to meet local roadside conditions. They should be healthy and vigorous, relatively free of insects and disease, and require little maintenance. To insure health and vigor, they must be selected for each site. Only species that are ecologically suited to the site as to soil, light, and moisture are likely to thrive. Immediate results cannot be expected. Several years of growth are required before planting becomes sufficiently dense.

The effect of buffer planting on snow drifting has not been explored in this report. In regions where snow is a factor, both the beneficial and the adverse effects should be considered.

CONCLUSION

I. What We Know

A. Traffic noise on primary highways and expressways is causing increased concern to both automotive and highway engineers.

B. Automotive engineers are directing research toward reducing noise in the motor vehicle:
1. Exhaust noise; 2. Tire squeal; 3. Gear howl.

C. Highway engineers are concerned in suppressing the noise which emanates from the highway to abutting property.

D. Traffic noise is more of a nuisance in quiet residential areas than in noisy commercial areas.

E. To be most effective, barriers, such as walls, embankments, and plantings, should be placed as close as practicable to the traveled way.

F. The most effective and economic method of abatement for each particular situation should be used:
1. Wider right-of-way and building set-backs; 2. Buffer planting;
3. Fences and walls; 4. Embankments; 5. Any combination of 1, 2, 3, and 4.

G. A close relationship exists between right-of-way, cross-section, and buffer-planting widths.

H. Buffer planting which provides privacy to the roadside dweller has a definite psychological value.

II. What We Do Not Know

A. What noise levels (loudness) are tolerable in:
1. Industrial and noisy commercial areas? 2. Close-in residential areas?

3. Quiet residential areas?

B. What methods are most effective and economical in reducing traffic noise to abutters?

C. What economic effect does traffic noise have on the use and value of land abutting major highways?

III. Research Is Needed to Answer the Above Questions

Field tests are needed to obtain data for general uniformity and agreement on:

A. Methods of measurement of highway noise from the standpoint of annoyance to roadside dwellers.

B. Noise levels acceptable for different land-use areas in which highways may be located (i. e., loudness above background noise).

C. Most effective and economical methods for abating (reducing) highway noise to abutters.

ILLUSTRATIONS

Figures 1, 2, and 3 are photographs of plantings installed before serious consideration had been given to noise abatement. Although these plantings were designed primarily as visual barriers, auditory benefits were gained.

Figure 1 shows an example of border planting in a built-up section of the Mount Vernon Memorial Highway in Virginia. The nearest corner of the house in the right foreground is about 40 ft. from the edge of the pavement. The planting width on the cut slope between the house and pavement averages 25 to 35 ft. This photograph shows the planting 15 years after completion of the highway. In this early 1930 design with mountable curb, no shoulder was provided for emergency use. Today, the planting would be set well back from the shoulder space to avoid encroachment on the traveled way.

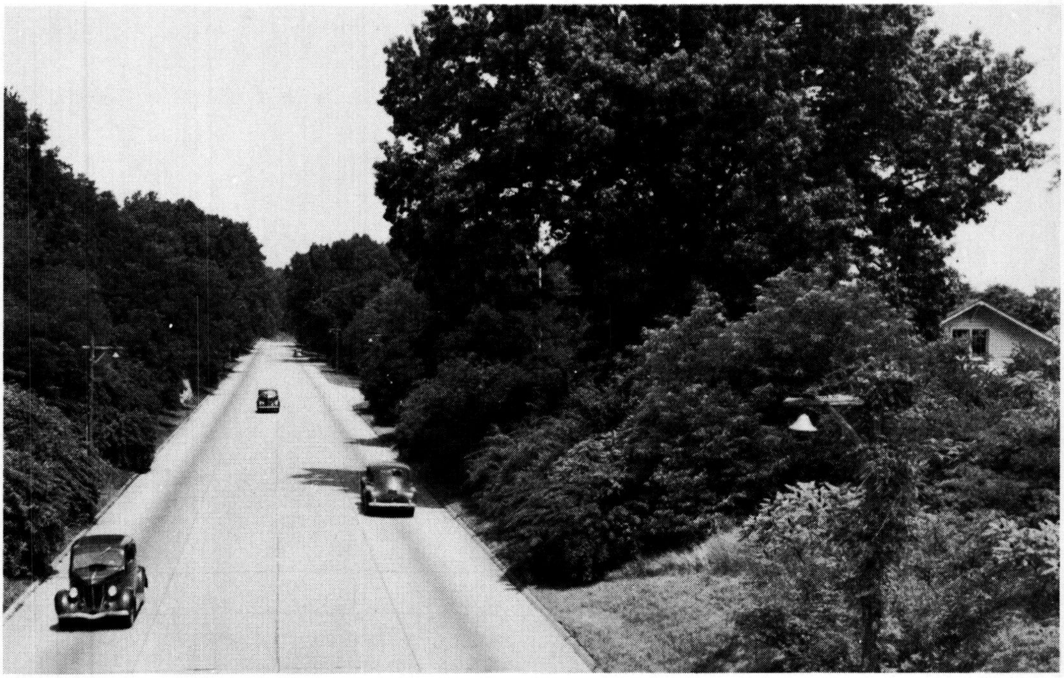

Figure 1. A depressed section of highway. The planting on the right 'insulates' the house from traffic noise. It serves the dual purpose of screening traffic from sight and sound. (Photo, courtesy of Bureau of Public Roads.)

Figure 2 shows an example of a raised type of highway with border planting on the embankment slopes. Lower road in foreground is a frontage or service road.

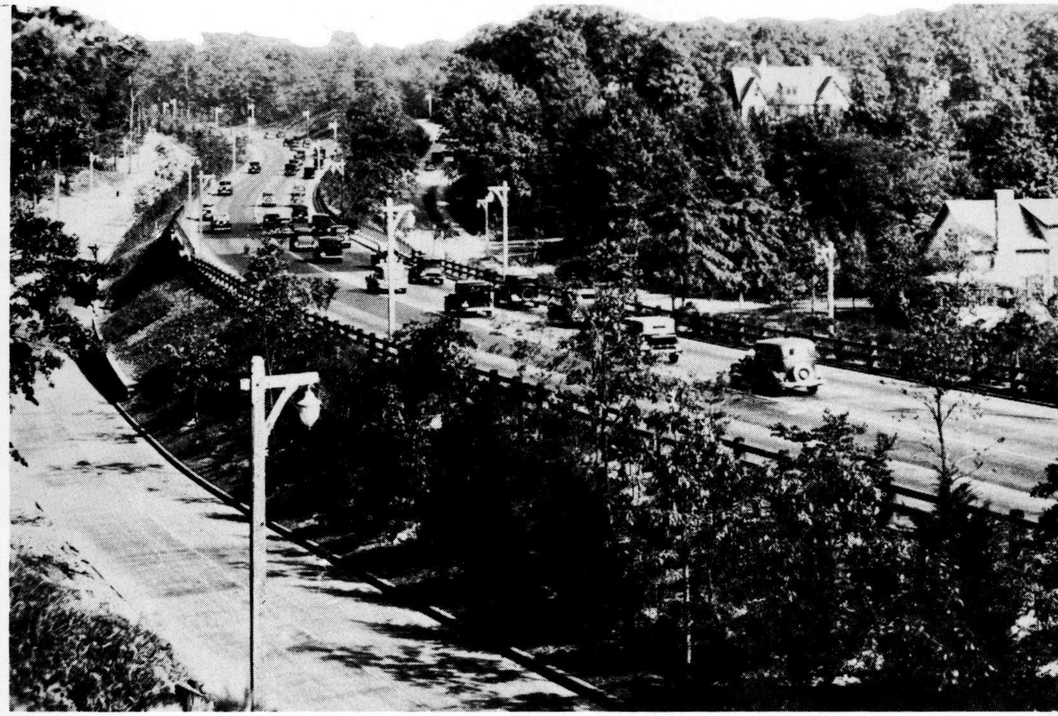

Figure 2. A raised section of highway. Abutting properties on the far side of the highway are well insulated from traffic noise by planting. (Photo, courtesy of Long Island State Park Commission.)

Figure 3 is an illustration of border planting about 40 ft. wide along a level type of cross section.

Figure 3. A level section of highway. The planting seen on the left insulates abutting properties from traffic noise. It serves the dual purpose of screening traffic from sight and sound. (Photo, courtesy of Bureau of Public Roads.)

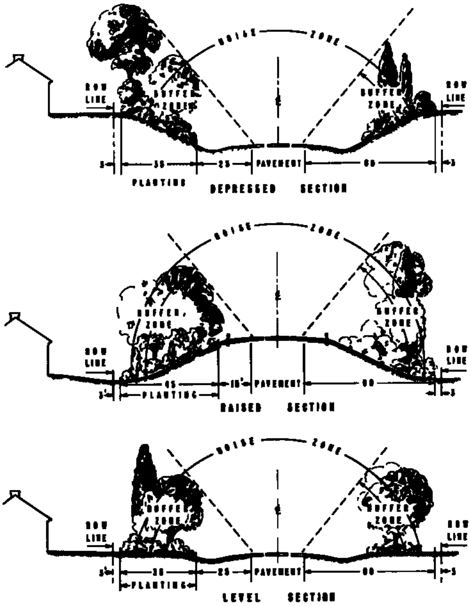

Figure 4. Assuming that buffer plantings will be limited to major highways where traffic is heaviest, and that AASHO standards are followed, a width of 60 ft. of right-of-way on each side of the pavement is desirable to provide space for a shoulder, gutter, and buffer-planting. This general statement applies to all types and widths of major highways and to the three general types of cross-section.

Sound radiates from the source and may be reflected. Highway noise is reflected upward from the depressed type of highways. Planting along highways may be effective in suppressing transmission of traffic noise to adjoining roadside areas.

Research is needed to determine the effectiveness of buffer planting on raised cross sections.

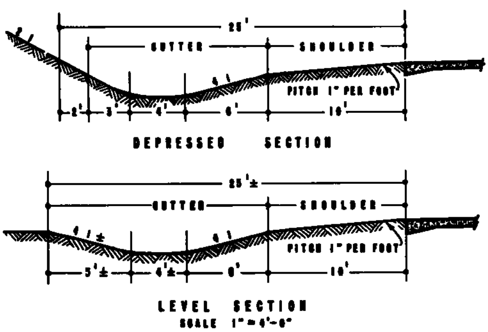

Figure 5.

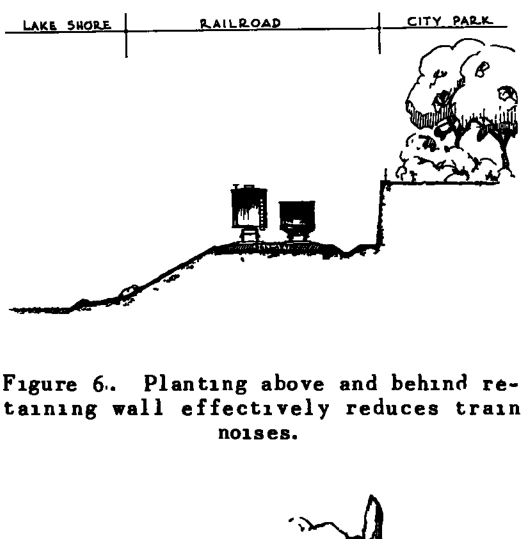

Figure 6. Planting above and behind retaining wall effectively reduces train noises.

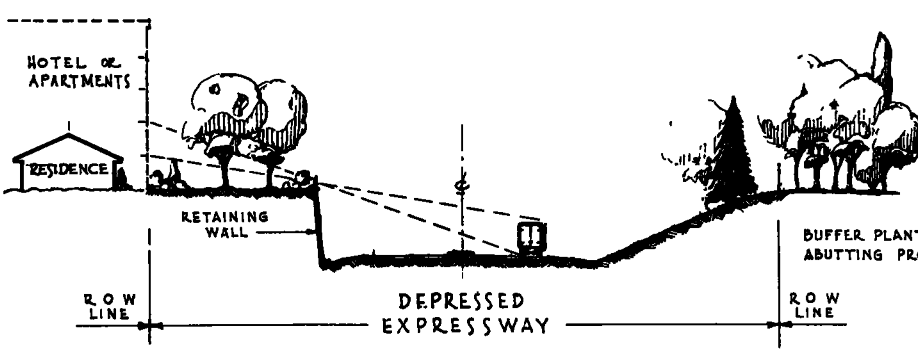

Figure 7. Highway noise was almost inaudible 100 ft. behind retaining wall and top of slope. The distance should be increased for multistory buildings.

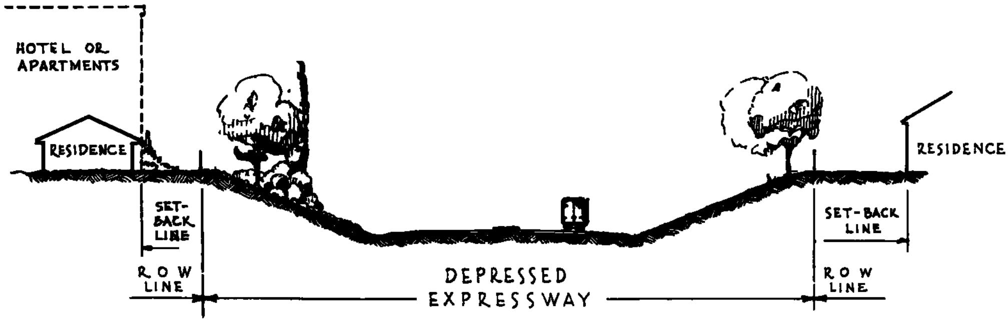

Figure 8. Depressing roadway level plus planting caused a large reduction in highway noise. Further reduction may be obtained by increased building setback.

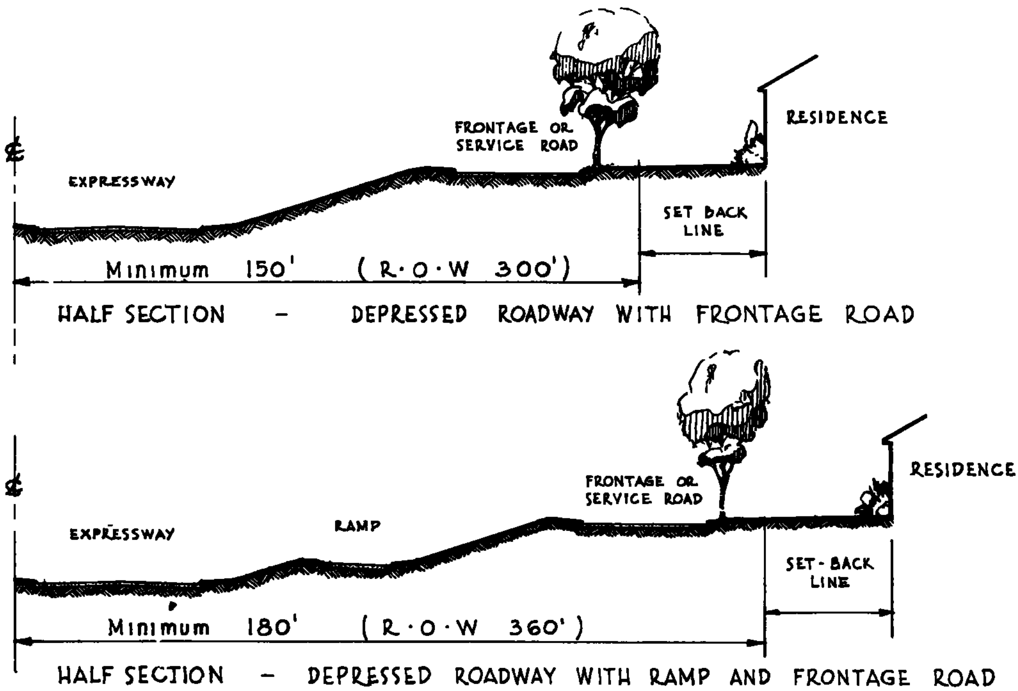

Figure 9. Distance from the main-traffic roadway is important in highway-noise abatement. Tree-lined frontage roads are effective. The Congress Street Expressway through suburban Maywood home sections of Chicago is an example. Arterial routes through developed residential communities should be planned to minimize the noise to abutters.

(Figures 4-9, courtesy Bureau of Public Roads.)

DISCUSSION

Nelson M. Wells. Is there any information on land values along expressways for areas where planting screens traffic noise and for areas where there is not planting screen?

Wilbur H. Simonson. We know of no information that is definite. Research along this line is needed. A book (1937) by Nolen and Hubbard, "Parkways and Land Values" shows the increase in land values of property adjacent to parkways in Westchester County, New York; in Boston; and in Kansas City, Missouri. There is also a 1951 report, "A Study of Land Values and Land Use Along the Gulf Freeway" (Houston to Galveston, Texas), made by L. V. Norris Engineering Co. for the Texas State Highway Department and the U. S. Bureau of Public Roads. It gives many interesting tables on changing land values along the Gulf Freeway. Neither of these publications, however, gives actual facts on the effect of buffer plantings on land values. More specific research is needed.

Frank H. Brant. In the information you have studied, is there any available equipment that could be used to determine the noise on each side of the barrier planting?

Simonson. Yes, equipment is available for noise measurements. Engineers interested in sound equipment should read the pamphlet by Leo L. Beranek, "Apparatus for Noise Measurement," (General Radio Co., Cambridge 39, Mass.) Various acoustical instruments are briefly described, such as sound level meters, analyzers, calibrators, recorders, etc.

Measuring sound is not a simple matter, but there is no reason why highway engineers cannot become proficient in it as they have in other specialized fields of highway engineering, as in soils, hydraulics, and aerial surveying (photogrammetry.)

Grover F. Nelson. What is the effect of the various types of plant material on absorbing sound? Are high-crowned trees as effective as low-crowned trees, and what about low trees and shrubs? On level sections should tall trees be planted next to the roadway with shrubs in the background, which, of course, is contrary to accepted landscape design?

Simonson. All types of trees and shrubs may be used in planting a buffer. On level sections, shrubs are needed to absorb noise near the ground. Small trees will baffle noise above the shrubs. Tall trees will absorb sound above the low trees. A planting which conforms to good landscape design will make a good buffer, provided it is dense, wide, and high enough. Plants of dense growth, whether shrubs, small trees, or large trees, are more effective than those that are more open in growth.

Research is needed to determine how much the various types of plants reduce noise and what minimum planting widths are necessary to be effective. At present we have only opinions but, as the report brings out, we need research for actual facts.

Nathan Cherniack. Are shrill noises more annoying? Jet planes have a quality of noise that is certainly disturbing. Trees would not help muffle airplane noise.

Simonson. This introductory report deals with highway noise only; airplane noise is a separate problem. Shrill noises, that is, high-frequency noises, are much more annoying than the low-pitched noises of low frequency. Jet planes have a very high, loud, disturbing noise, which is really a serious problem on land use. I would refer you to "Urban Land" (Reference (9), where Dr. H. C. Hardy of Armour Research Foundation reported that jet-plane noise may be annoying to residents four or five miles away.

SELECTED REFERENCES
(With comments pertaining to noise abatement along highways)

1. Finch, D. M., and Andrews, Basil, "Highway Noise and Its Measurements," Research Report No. 6, The Institute of Transportation and Traffic Engineering, University of California, Berkeley, 6 pp., multilith, (March) 1951. - - This report deals with highway noise caused by mufflers on heavy trucks. The concluding paragraph of the report gives this concise statement:

"The highway noise problem is one of reducing the noise output of large trucks. In

seeking to do this there are four fields of endeavor, all of which need to be pursued. These are: (1) driver education, (2) elimination of unnecessary stops, (3) design of roadway, roadside, and adjacent structures, and (4) reduction of the amount of noise which a truck makes under any and all conditions of operation. This last-mentioned task requires some convenient method of measuring loudness in the field, in order that quantitative values may be written into the codes and may be determined by law enforcement officers. The study of this phase of the problem is being continued as a part of the research activities of the Institute of Transportation and Traffic Engineering at the University of California, Berkeley."

1-A. Andrews, Basil, and Finch, Dan M., "Truck-Noise Measurement," Highway Research Board, Proceedings, pp. 456-465 (December) 1951. - - Field and laboratory tests were made on noises produced by large trucks equipped with different mufflers, in conjunction with the California Motor Transport Associations and the California Highway Patrol. Evaluations of the tests indicate that the American Standards Association sound-level meter can be used as a satisfactory instrument to indicate the annoyance value of truck noise, if used on the proper scale and set up in the proper manner.

2. Kyropoulos, Peter, "Traffic Noise," Traffic Quarterly, pp. 31-43 (January) 1948. The two concluding paragraphs of this article on traffic noise are significant and timely for highway planners and designers:

"In connection with parkway planning, it is well to point out that sound radiates from the source and may be reflected. Depressed highways, therefore, reflect the bulk of highway noise upwards, especially if secondary reflection is avoided by planting on the slopes. Planting along highways, even if not depressed, is very effective in suppressing the noise transmission to adjoining areas. Elevated structures are unfavorable. The sound radiation reaches a maximum of area and the structure itself has a tendency to pick up low-frequency rumbles (e.g. tire-thumping at pavement joints) and transmitting them in the surroundings.

"In conclusion, it should be said that only recently have engineers and the public become actively noise-conscious. As a result, relatively little is known about and little has been done towards measurement and analysis of traffic noise. It can be hoped, however, that as more data become available, interpretation and prediction will become conclusive."[2]

3. Mills, Edwin L., "Recent Developments in Instrumentation and Control of Traffic Noise," Technical Bulletin Series No. 1, Western Highway Institute, 9 pp. multilith, (March 29) 1950. - - This bulletin discusses "excessive" noise and its measurement. Tests were made using existing and recently designed types of mufflers on several of the larger diesel engines, on the open highway, with loaded trucks ascending a 4-percent grade under full throttle. Although this study was limited to exhaust noise, it was not intended to imply that this is the only important traffic noise, or that its elimination will solve the entire noise problem.

4. AMA Motor Truck Technical Subcommittee, Fred B. Lautzenhiser, Chairman, "The Automotive Traffic Noise Problem," 4 pp. multilith, (May 24) 1951. - - This material on automotive traffic noise was requested for the (June) 1951 meeting of the AMA Engineering Advisory Committee with the Engineering and Inspection Committee of the American Association of Motor Vehicle Administrators. After numerous attempts at unsound traffic-noise legislation and many complaints from operators, the AMA Motor Truck Committee requested the Society of Automotive Engineers to make a study of the subject. The SAE set up a Special Automotive Traffic Noise Subcommittee (with Mr. Lautzenhiser as Chairman) which included some of the outstanding sound physicists in the United States. Field investigations were made in the middle west, and in the east.

"In the meantime (1948-1951), both the University of California and the Motor Truck Association of Southern California undertook the solution of the traffic noise problem. "Listeners' juries" were used a number of times; however, neither satisfactory truck-engine exhaust-noise mufflers, nor instrumentation for the measurement, evaluation, and correlation of such noise with the human ear, were available. Committees were set up (1950 Spring Meeting) by the American Trucking Association to go into the matter

[2] Recent data are now available: See References (8) and (16).

further. At the May, 1951, meeting at San Francisco, the ATA Equipment Advisory Committee resolved that the Armour Research Foundation be retained as a consultant on this problem." (See also Reference (16).)

5. Noise Abatement Commission, Department of Health, City of New York, "City Noise," 308 pp. illustrated and indexed, 1930. - - This early report (nearly 25 years ago) is still useful for those not specialists in the subject. A detailed explanation of the decibel scale of noise levels is presented on pages 32-34. It is important to understand that decibels do not measure absolute units, but are instead, convenient symbols for expressing a ratio. For example, the difference between 10 in. and 20 in. is the same as that between 90 and 100 in. But between sounds of 10 and 20 decibels (db) above the threshold of hearing, there is an intensity difference of 90, while the difference between sounds of 90 and 100 decibels is 9 billion.

6. Bonvallet, G. L., "Levels and Spectra of Traffic, Industrial, and Residential Area Noise," Journal of the Acousitcal Society of America. Vol. 23, No. 4, pp. 435-440 (July) 1951. - - A survey of city noise in the Chicago area was initiated in 1947. This report describes traffic, industrial, and residential-area noise with a view toward formulating a basis for acceptable levels. This survey shows that the three worst noise sources in American cities are the truck, the locomotive, and the airplane. It was concluded from the survey data that there probably is little doubt of the advantage of octave-band data in describing noise loudness and objectionable qualities.

7. Callaway, Daniel B., "Instrumentation and Techniques for Measurement and Evaluation of Industrial Noise," Second Annual National Noise Abatement Symposium, Chicago, Ill., pp. 64-74 Proceedings, 108 pp. illustrated, (October 5) 1951. - - On page 74, Dr. Daniel B. Callaway, Physicist, Acoustics and Vibrations Section, Armour Research Foundation, Chicago, Ill., summarized his discussion of the development of the loudness calculation techniques as follows:

"1. Much of the noise occurring in industry is broad-band in nature, and reliable determination of its loudness cannot be made by use of the sound-level meter alone.

"2. Since the ear acts as a frequency analyzer, some sort of frequency analysis must be obtained as a preliminary step toward determining the loudness of a noise.

"3. By means of octave frequency analyses, proper weighting of the sound levels of individual octave bands, and summation of the weighted contributions, the loudness of broad-band noises can be determined."

8. Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill., "Noise and Vibration Problems Associated with Traffic on Edens Espressway," Report No. 1 (Project No. 1-1167A) for Cook County Highway Department, Chicago, Ill., 40 pp. including Appendix Data, multilith, (April 30) 1952. - - This study was made to evaluate the loudness of traffic noises, using a loudness scale that would agree with the subjective judgment of those exposed to the noise. Such a scale is described and the resulting loudnesses reported. There is no simple solution to the problem of the objectionable nature of traffic noises due to (a) the fact that trucks are the noise source, and these not only are noisy but are visible signs of commercial activity in a previously residential area; and (b) the intermittent nature of the noises and their occurrence at night. The noises were measured and compared, but it was not expected that a solution would be found for these difficulties in this study.

9. Hardy, H.C., "Measuring Noise in Cities," Urban Land, Vol. 11, No. 10, pp. 3-5 (November) 1952, (Also: in Highway Research Abstracts, February, 1953.) - - This article by Dr. H.C. Hardy is illustrated by a chart of city noises showing the loudness in sones of various city noises evaluated from the measured levels. (This chart was reproduced on p. 3 of Highway Research Abstracts (February, 1953.)

10. The University of Michigan, School of Public Health and The Institute of Industrial Health, "The Acoustical Spectrum, Sound — Wanted and Unwanted," 192 pp. illustrated, (February 5-8) 1952. - - This contains the lectures presented at the in-service training course at Ann Arbor, Mich., covering noise — causes, effects, measurement, costs, control. "Sound Control in Community Layout, Housing, and Building Design," p. 136-141, by Ralph J. Johnson and Roy O. McCaldin.

11. Knudsen, Verne O. and Harris, Cyril M., "Acoustical Designing in Architecture," 457 pp. illustrated, 1950. - - This book includes, "Siting and Planning Against

Noise," p. 222, and "Grading and Landscaping," p. 223. The following appears:

"Interurban automobile and truck traffic should be routed around, not through, areas that have been zoned for schools, residences, and hospitals; express highways that must pass through zones requiring quiet surroundings should be isolated by means of embankments or parapets along the outer edges of the highway; . . . parks and landscaping should be planned to impede the propagation of noise into quiet zones . . ."

This is the only reference furnishing quantitative data on absorption of sound by planting, such as, on p. 223:

"A cypress hedge 2 ft. thick has sound-obstructing value of about 4 db. Hedges or trees with dense foliage act as sound absorbers and reflectors, and their effectiveness increases with the extent (thickness, height, and density) of growth . . . dense planting can be used to attenuate noises to levels that will facilitate the architect's and builder's problem of providing adequate noise insulation for court rooms, hotels, residences, and other buildings." (Motels on highways.)

12. American Association State Highway Officials (AASHO), "Highway Noise Reduced Through Border Plantings," American Highways, Vol. XXXII, No. 3, p. 10 (July) 1953. - - This short article indicates that although no scientific measurements have been made of noise reduction on highways by intensive planting, the state engineers, from personal observation, concluded that there was a satisfactory reduction in noise at adjacent residences due to planting.

13. Pierce, Bert, "Trees Help to Cut Noise on Highways," The New York Times, August 8, 1953. - - The New York Times article (August 8, 1953) describes the results on parkways in New York City:

"Landscaping absorbs considerable noise which otherwise makes the abutting area less desirable for residents . . . (the) aim in the case of parkways (is) to create ribbon or shoestring parks as distinguished from mere gasoline gullies. Both car passengers and near-by residents benefit equally.

"Although mixed-traffic expressways, which provide for trucks as well as passenger vehicles, are being planted in a somewhat similar manner . . . some time must elapse before plant material will act as an effective screen for passing vehicles or as a noise deterrent.

"On some of the older arteries such as Grand Central Parkway, where it was impossible to persuade officials to acquire a sufficient right-of-way, we have had to resort to intensive planting," Mr. Moses said. "This, however, is rather a poor substitute for the real thing, the genuine ribbon park."

14. O'Harrow, Dennis, "City Planning for Reduced Noise," The Fourth Annual National Noise Abatement Symposium, Chicago, Ill. (October 23) 1953. - - The abatement of noise was discussed as a planning problem in city and industrial-site development. It is obvious that as urban concentration increases, we produce increased noise. In city planning, possibilities are more in future, than in present, prevention: we are awakening to the value of space in design functions.

15. Fugill, A. P., "Outdoor Noise Problems at Industrial Plants," The National Noise Abatement Symposium, Chicago, Ill., (Fourth) October 24, 1953. - - Mr. Fugill gave a realistic appraisal of the noise problem and pointed out that those faced with the problem can certainly do something. "Don't let not knowing all the answers prevent your starting to do something," he said. If a person is annoyed, no amount of statistics or standards will change his attitude, according to the experience of the Detroit Edison Co. "Planting," he said, "may change sound pitch and make it more agreeable, a psychological value; but there is some question about the actual amount of reduction. The Edison Co. has tried landscaping, but not too helpful for their needs. Main value was in the fact that people cannot see the transformers. This reduced complaints."

16. Kibbee, Lewis C., "We Can Reduce Truck Noise," The Fourth Annual National Noise Abatement Symposium, Chicago, Ill. (October 24) 1953. - - The truck associations realized traffic noise was a public relations problem and called in the Armour Research Foundation as experts on acoustics. Conferences showed the possibility that something could actually be done. In 1952, they began to get at the root of the trouble with an answer that solves the problem. Three steps were involved: (1) know how to measure; (2) know what it is; and (3) control (test procedure) at factory.