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Bulletin 110

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Abatement of Highway Noise and Fumes

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2101 Constitution Avenue Washington 25, D. C.

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Bulletin 110

Abatement of Highway Noise and Fumes

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HRB:M-321

Foreword

This bulletin contains three separate studies. Two reports on abatement of highway noise are combined with one paper on motor vehicle noise studies. Heretofore, highway engineers have been primarily concerned with providing service to the user of the highway. Today, this concern has broadened to consider the effect on people living along the highway. A search of published material provides much information on industrial noise and its measurement, but relatively little data on the abatement of traffic noise to abutters. Selected references with comments pertaining to noise abatement along highways are included to orient the highway engineer. This bulletin brings under one cover (1) a review of what has been accomplished, (2) a summary of the present status of technical aspects in relation to highway noise, and (3) a proposed program for field tests to measure and evaluate noise abatement methods.

In 1952 the HRB set up a special task committee to conduct a study on roadside design to reduce traffic noise, dust, and fumes. The 1953 study of this task committee was published in the 1954 annual report of the Committee on Roadside Development (publication 318, pp. 55-78,) a condensed version of which is here included.

The 1954 study is in two parts. Part 1 presents source information collected since publication of the 1953 study on abating highway noise and lays the groundwork for needed research on the various phases of this timely subject. Part 2, "Preliminary Report on Reduction of Fumes with Special Reference to Roadside Design" introduces the reader to the danger of highway traffic fumes, hitherto given little or no thought by the average person. Selected references include comments.

The paper, "Motor Vehicle Noise Studies," by D. M. Finch, University of California Research Engineer, is likewise in two parts. Part 1 covers the data obtained on noise levels adjacent to expressway-type highways under conditions that are typical of many such areas in the United States. Part 2 covers the project of analyzing the noise spectrum for various types of vehicles as observed on the road and as measured on a test dynamometer. Jury appraisals of the latter noise spectra were also obtained and correlations determined between jury ratings and measurements. The paper is a comprehensive appraisal of motor vehicle noise and explains concisely the difference between the terms "decibel," "phons," and "sones."

The reader has the opportunity to become acquainted with facts presented in a non-technical way as to conditions that might confront him in his own front yard when that new highway begins to teem with the never-ending rumble of traffic day and night.

It is hoped that this publication will be useful to those interested in the fields covered, since much of the information presented is from widely scattered sources.

Acknowledgment is made of the helpful assistance of committee members in the preparation of the 1953 and 1954 studies. Grateful acknowledgment is made of assistance by George G. Holley* particularly in the preparation of Part 2 on "Fumes." Appreciation is also expressed for cooperation of Mrs. Helen Harrow in the preparation of the manuscript.

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*Deceased June 29, 1955

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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)

Wilbur H. Simonson, Chairman, Chief, Roadside Section
Bureau of Public Roads

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.

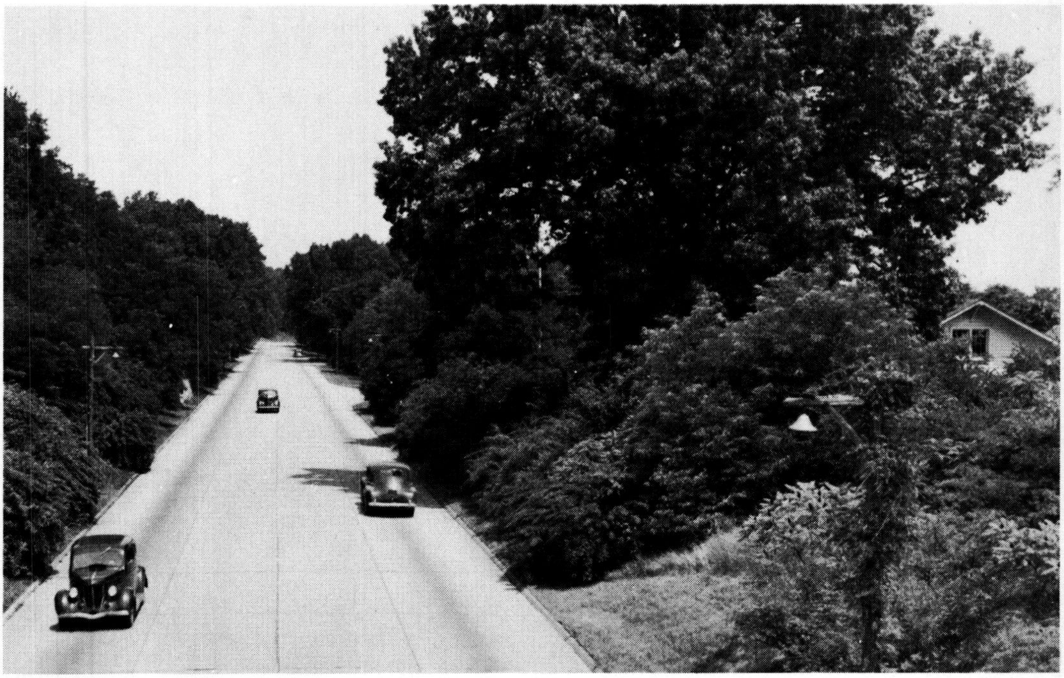

Figure 1. A depressed section of highway. The planting on the right 'insulates' the house from traffic noise. It serves the dual purpose of screening traffic from sight and sound. (Photo, courtesy of Bureau of Public Roads.)

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.

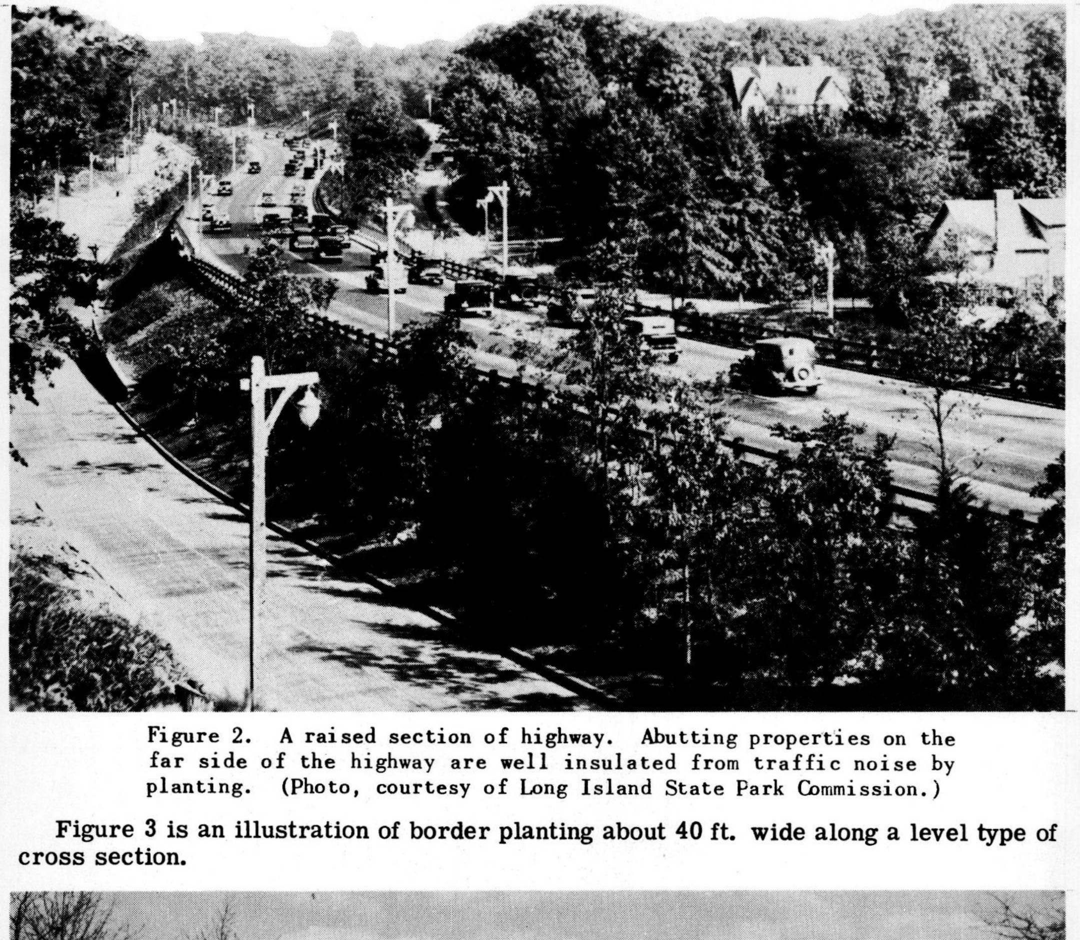

Figure 2. A raised section of highway. Abutting properties on the far side of the highway are well insulated from traffic noise by planting. (Photo, courtesy of Long Island State Park Commission.)

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

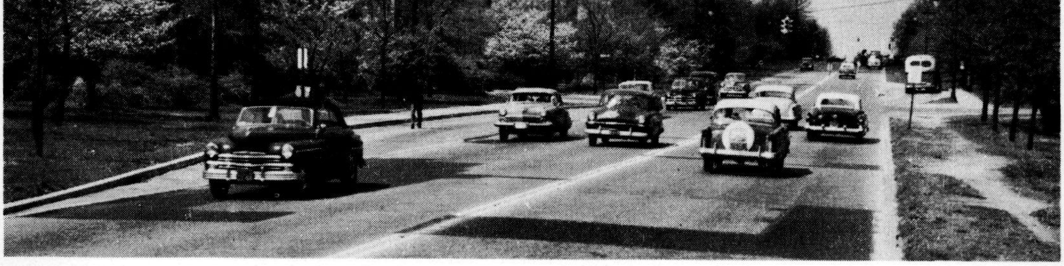

Figure 3. A level section of highway. The planting seen on the left insulates abutting properties from traffic noise. It serves the dual purpose of screening traffic from sight and sound. (Photo, courtesy of Bureau of Public Roads.)

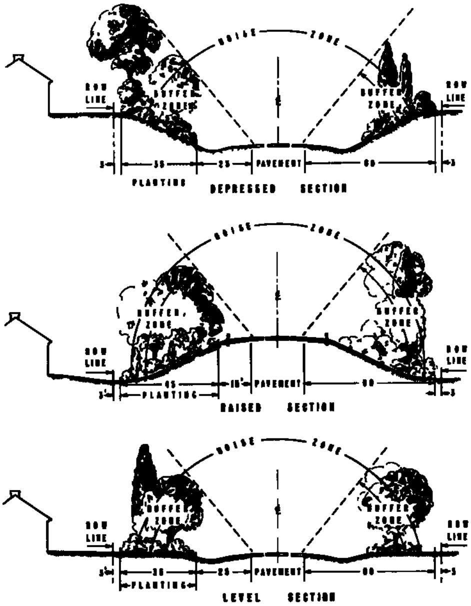

Figure 4. Assuming that buffer plantings will be limited to major highways where traffic is heaviest, and that AASHO standards are followed, a width of 60 ft. of right-of-way on each side of the pavement is desirable to provide space for a shoulder, gutter, and buffer-planting. This general statement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

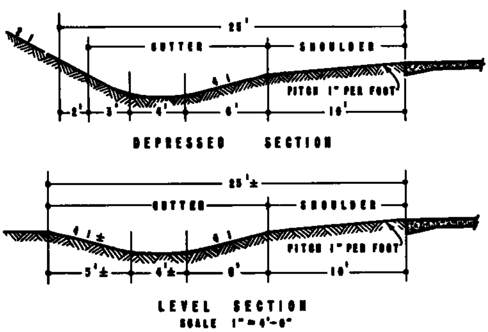

Figure 5.

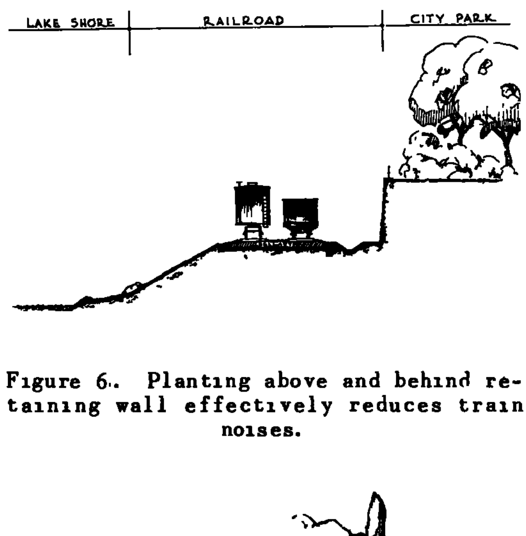

Figure 6. Planting above and behind retaining wall effectively reduces train noises.

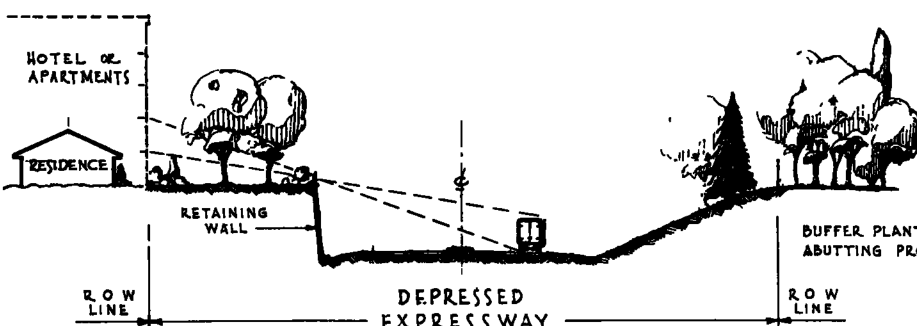

Figure 7. Highway noise was almost inaudible 100 ft. behind retaining wall and top of slope. The distance should be increased for multistory buildings.

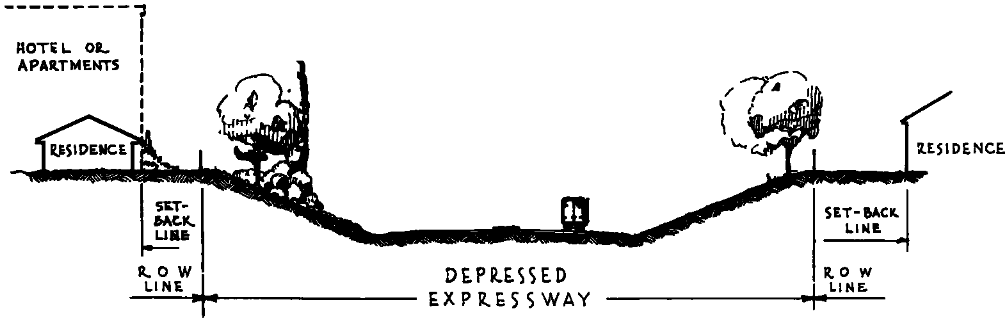

Figure 8. Depressing roadway level plus planting caused a large reduction in highway noise. Further reduction may be obtained by increased building setback.

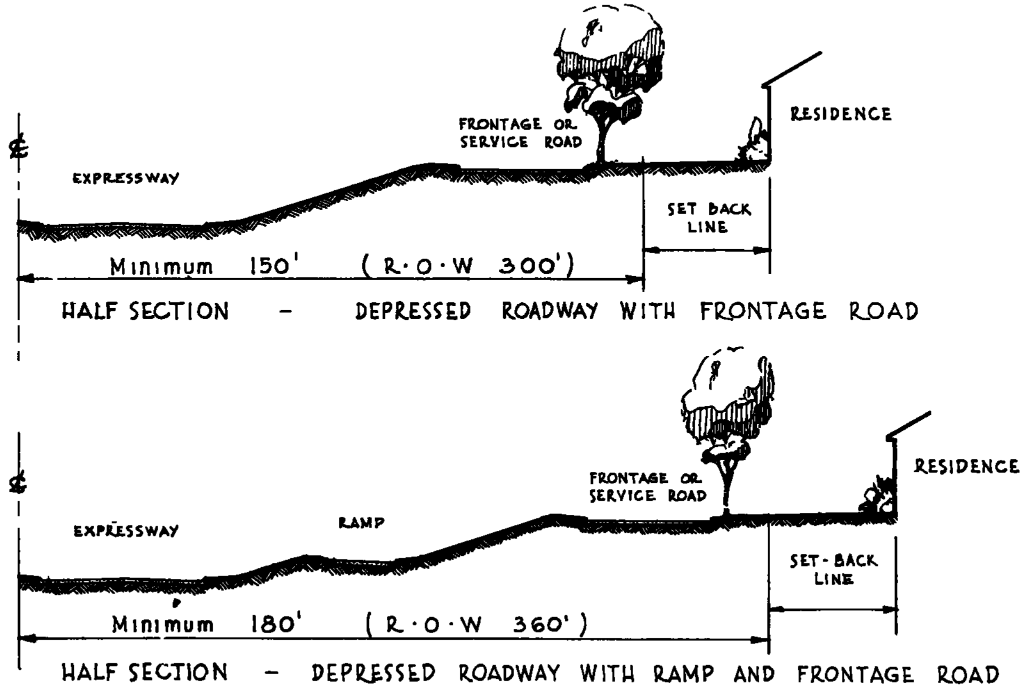

Figure 9. Distance from the main-traffic roadway is important in highway-noise abatement. Tree-lined frontage roads are effective. The Congress Street Expressway through suburban Maywood home sections of Chicago is an example. Arterial routes through developed residential communities should be planned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

Motor Vehicle Noise Studies

D. M. FINCH, Research Engineer
Institute of Transportation and Traffic Engineering
University of California

THE noise associated with motor vehicles has been receiving more and more attention in recent years. This is due partly to the general public concern about increases in all kinds of noise in every day life, such as that from home appliances, office machines, jet planes and so on. It is also due to the tremendous increase in the volume of automobile and truck noises which is a consequence of both greater engine power and more vehicles.

As a result of these trends, the highway has become a serious source of disturbing noise. Since 1944, the number of automobiles has increased 76 percent, and trucks 109 percent. The average size of truck engines has also increased - and 600-hp diesel truck engines are being advertised. These increases have brought a corresponding increase in the number of complaints of excessive noise. More and more people are saying that "there ought to be a law against excessive highway noise".

The prospects for the future all point to an intensification of this problem. The number of automobiles and the number and size of trucks will doubtless continue to increase. It is to be expected that heavy traffic will become more and more channelized on freeways and that many of these freeways will pass through districts where there may be vigorous objections to the roar of traffic.

These matters have been the subject of continuing investigation by the Institute of Transportation and Traffic Engineering at the University of California. The present study is concerned with some of the characteristics of noise generated by traffic streams. Test sites were selected so as to be representative of various operating conditions on facilities of the expressway type.

As a subject of mutual interest to the Institute of Transportation and Traffic Engineering and the California Division of Highways, a part of this study was undertaken as a joint project, conducted under an agreement between the University and the Division. The Institute is grateful to all those who assisted in this study, and particularly to John L. Beaton, R. M. Gillis, Rudolph Hess, and F. N. Hveem, all of the Division of Highways, and to W. A. Partridge, J. A. Fogle, and C. W. LeRoy, of the Institute staff.

There are two main objectives in this study: (1) to determine the magnitudes of the noises associated with various types of vehicles and highway facilities, and (2) to attempt to evaluate the noises in terms of physical measurements that correlate with subjective appraisals.

The problems of measurement and evaluation of vehicle noises are technically complicated and they have not been completely resolved. For example, the California Vehicle Code refers to "unusual" or "excessive" noises. There is a need for a definition of "excessive noise" and a practical, convenient method of measurement that may be supported by jury appraisal. This standard should account for the annoyance of the noise as well as its loudness. Annoyance usually increases with loudness, but not always. For instance, intermittent noises are usually considered more annoying than continuous ones, and noises containing high-frequency components are more objectionable than those of the same intensity which are composed of low-frequency components. Probably some of the most bothersome noises from vehicles on the highway occur when the vehicles are operated at high engine speeds during acceleration and just prior to shifting gears. This condition gives rise to a combination of high-frequency components and an intermittent noise pattern, as well as high intensity.

The time-pattern factor for intermittent noises has at least two components. The first involves the length of time the noise remains at an annoying level;

most people feel that a noise is less annoying if its duration is short. In the case of highway noise, this is determined mainly by the time the vehicle remains within a certain distance of the person or persons who hear it. The second component involves the length of time between passing vehicles which are responsible for the noise; noises that occur periodically are generally considered less annoying than those which occur at irregular intervals.

Annoyance is a subjective quality, so a precise, quantitative expression of it probably cannot be found. Also loudness, by physical definition, is subjective. The techniques of measurement that have been used in this study permit comparisons to be made on either an annoyance, loudness, or intensity basis if the correlations that are shown between the meter readings and the subjective quantities are considered adequate.

Scope

The material presented in this paper is in two parts corresponding to the objectives already mentioned. Part I covers the data obtained on noise levels adjacent to expressway-type highways under conditions that are typical of many such areas in the United States. Part II covers the project of analyzing the noise spectrum from various types of vehicles as observed on the road and as measured on a test dynamometer. Jury appraisals of the latter noise spectra were also obtained and correlations determined between jury ratings and measurements.

Part 1
Noise Measurements on Expressway-Type Facilities

● The objective of the investigation was to obtain data on noise levels adjacent to freeways under conditions that are typical of many areas in the United States. Data were collected at 15 test locations in California, scattered from Vallejo in the central part of the State, to Los Angeles in the south. The locations were of five types, as follows:

1. Inclined. A rural freeway with a long steep grade. The extended incline created a condition where maximum noise could be determined for representative traffic under full-load, steady-state operation.
2. Intersection. An intersection on a freeway in an area having high traffic volumes. This permitted noise measurements both for continuous traffic movement and for vehicles accelerating from a stop.
3. Level. A level, high-traffic-volume freeway. Here traffic could be observed when operating near maximum permitted speeds.
4. Elevated. An elevated section of freeway. This served to indicate the effect of having the noise source above the surrounding terrain.
5. Cut. A freeway section in a cut. Here the effect of absorbing or reflecting surfaces could be evaluated.

TEST LOCATIONS

The following descriptions of each type of test location indicate the characteristics of the actual freeway sections investigated.

1. Inclined Type

American Canyon Highway, US 40, north of Vallejo, Calif. (Figure 1). A 4-lane divided highway with a positive grade for northbound traffic and a negative grade for southbound traffic. Division of northbound and southbound traffic by means of a raised island approximately 6 ft. wide and bounded by an 8-in. curb on each side. The pavement surface is asphalt. Surround: to the west, a steep negative slope; to the east, fairly level for 22 ft., then low rolling hills; no obstructions or reflecting surfaces of

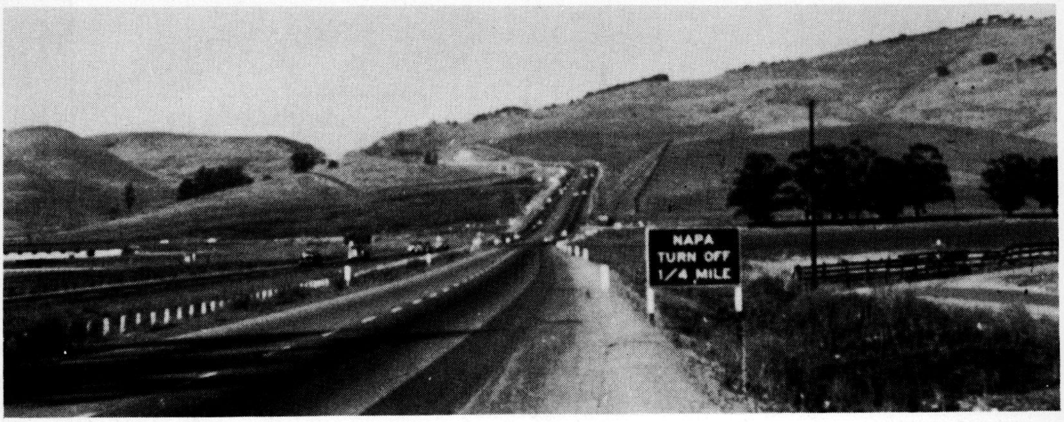

Figure 1.

any significance within 100 ft. of any test site. Test sites were located on the east side of the highway.

2. Intersection Type

Washington Blvd. and Telegraph Rd., Los Angeles, Calif. (Figure 2). An intersection of two 4-lane highways. An elevated section of freeway, approximately 300 ft. away, created a high noise level background. The east side of the intersection was bounded by open flat land. On the west side of the intersection was a 10- to 15-ft. fill, which has a section of the Santa Ana Freeway. Eastbound traffic on Washington Blvd. approaches the intersection as it ascends from an underpass beneath the freeway. Reflections of sound from large buildings or the fill on the west side of the highway were probably negligible, owing to their distance from the test sites and the high background noise level due to direct transmission.

Road surfaces were asphalt. With the exception of the eastbound traffic lanes, all approaches were level.

Traffic was controlled by a simple two-phase controller in conjunction with three-color traffic signals. Traffic was handled in two movements, left turns being made simultaneously with the movement of through traffic.

The test sites for this location were at the usual distances of 50, 150, and 300 ft., but were measured along a line approximately bisecting the angle of the corner.

Meter readings and tape recordings were made only of traffic moving on Washington Blvd.

3. Level Type

East Shore Freeway near Oakland Airport, San Leandro, Calif. A 4-lane divided highway section. The pavement was concrete or concrete with an asphalt surface. The

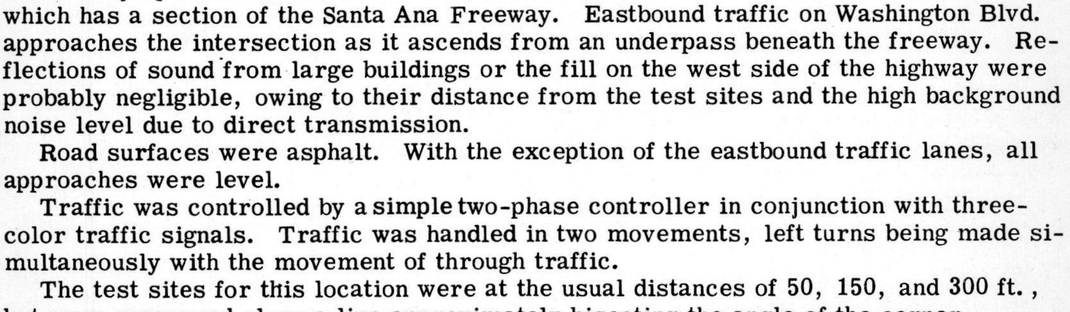

Figure 2.

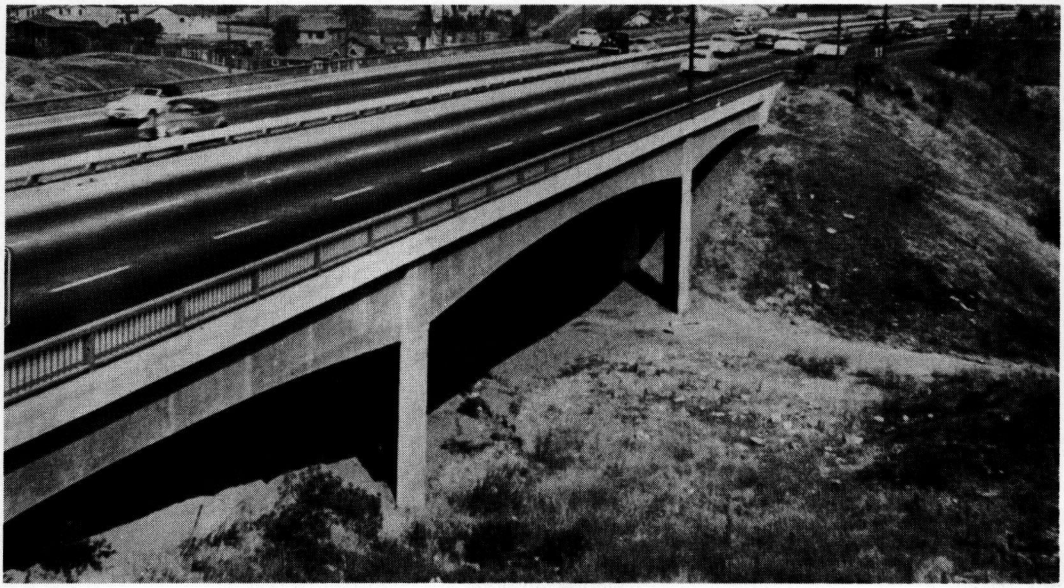

Figure 3.

surrounding terrain was level land with no obstructions or reflecting surfaces. Opposing traffic flows were separated by a concrete island which extended down the center of the roadway. Highway was straight and level.

4. Elevated Type

Santa Ana Freeway at Soto St., Los Angeles, (Figure 3). A 6-lane divided highway. The freeway section was on a bridge which was buttressed at each extremity by a fill. Opposing traffic lanes were divided by a concrete island down the centerline upon which was a steel railing. The bridge structure was concrete. The test sites ranged from 30 to 50 ft. below the level of the roadbed.

5. Cut Type

Hollywood Freeway: Cahuenga Pass near Barham Blvd., Los Angeles (Figure 4). Six main center lanes, two secondary lanes on either side of the 6 center lanes, and two turn lanes on the outside on each side making a total of 14 lanes. The six center lanes pass through an underpass. All lanes have a slight grade, as can be seen in the photograph. Pavement was concrete. The cut depth was 7 to 8 ft., and the center 10 lanes were bounded by concrete walls. Opposing traffic lanes were divided by ten feet

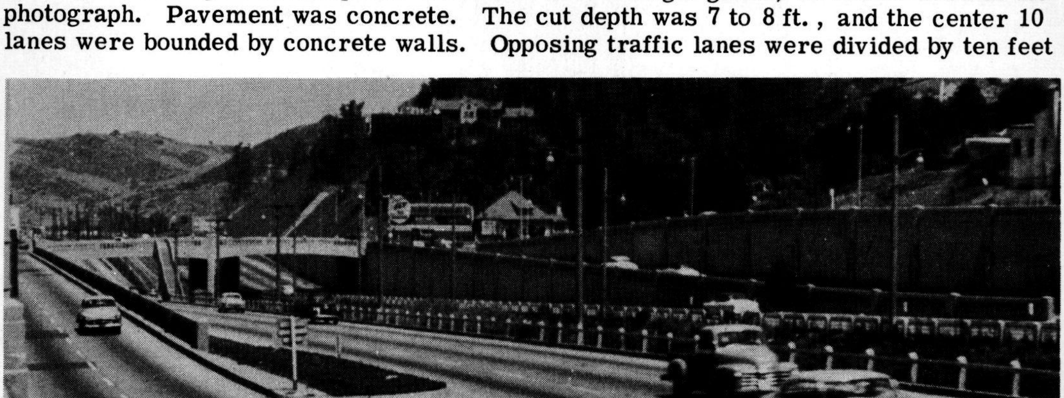

Figure 4.

of land. The overpass was approximately 75 feet northwest of the test location. Hills extended along the boundary of the freeway, parallel to its path.

TEST PROCEDURE

At each location instruments were set up to measure the vehicle noises from 50, 150, and 300 ft. away from the centerline of the nearest traffic lane (except that no 300-ft. readings were obtained at the one inclined-type location).

The sound level instruments were standard ASA type equipment and are described in detail in Reference 1. Adequate calibration and checking procedures were used to insure accurate readings.

The sampling of vehicles was random, but each situation was recorded both on magnetic tape and on data sheets so that the type of vehicle could be identified. The coding system used for vehicle identification and a complete description of the test set-up is given in Reference 2. An attempt was made to obtain at least 10 readings on a given class and type of vehicle so that the measurements would have reasonable significance. This was not possible at all locations because of the predominance of one or more types of vehicles. The data are given on the summary data sheets in Reference 2.

Three meter readings were taken on each test vehicle, one meter being set on each of the three (A, B, and C) meter scales, and three test distances from the highway were utilized. Therefore, each tabulation of the results for a particular type of freeway section has nine independent parts: one result for each of the three scale readings at each of the three test distances. For this reason, it is impractical to attempt to present all the results in the form of independent statements. Some of the more outstanding results will be presented here, but it is suggested that reference be made to the tabular summaries which may be found in Reference 2 for detail studies.

Several problems arose during the course of the work that could not be predicted in advance. Lack of a stable portable power supply was one of the primary obstacles. Since the tape recorder employed synchronous motors to drive the tape, a frequency-stable power supply was essential. Several different portable generators were used as a power supply but none was completely satisfactory in this respect. Owing to this difficulty, some of the magnetic tape was not acceptable for frequency analysis.

Increasing winds at the test locations presented additional problems, some of which went unsolved. Screening the microphones with silk cloth reduced the erratic meter indications due to wind by a significant amount, but the effect of the wind upon the indicated sound level was sometimes indeterminate. The change in the effective distance through which the sound had to travel due to the wind was calculable, provided the wind was constant, but gustiness created effects which could only be estimated. It was not feasible to estimate these effects or to calculate correction factors for every reading taken. Thus the wind, when present, presented an uncontrollable source of error that our technique could not accommodate.

The ASA type sound level meter has several advantages over other possible types of equipment, some of which are: (1) high degree of portability, (2) rugged construction, (3) rapid and continuous indication, (4) immediate availability of results, and (5) absolute numerical evaluation, as opposed to arbitrary evaluation required by some methods.

TEST RESULTS AND DISCUSSION

Any large group of data such as collected in this study affords the possibility of a great number of analyses. The analyses submitted herewith were limited to those considered to be most significant to the freeway problem. The complete data are tabulated in Reference 2 for any additional studies that may be desired.

The measured levels of the noises of vehicles passing the test location depend to some degree upon the background level, therefore, the background levels existing at the time of the tests are considered first (see Table 1). By way of explanation, the background level is that noise measured by the meters which exists because of the nature of the surrounding area and the activity taking place therein. This includes traffic noise which is not due to the vehicle or vehicles specifically under test. If the background level is

TABLE 1
AVERAGE BACKGROUND NOISE LEVELS

Type of Location	Test Distance feet	Decibels A Scale	B Scale	C Scale
1. Inclined	50	50	59	69
	150	48	58	62
2 Intersection	50	57	67	76
	150	52	64	73
	300	52	63	69
3 Level	50	48	56	65
	150	46	56	72
	300	43	55	66
4. Elevated	50	59	65	72
	150	53	56	63
	300	50	55	64
5 Cut	50	59	65	72
	150	52	60	68
	300	46	58	64
Averages for all locations	50	52	60	69
	150	50	58	68
	300	48	58	66

sufficiently high, the noise of a passing vehicle may not increase the meter reading by a measurable amount.

The background level also plays a large part in the relative annoyance of vehicles. For example, if the background level is relatively low, traffic noise may seem louder to the ear than it would seem if masked by a relatively high background level. The background noises of Table 1 are normal values for daytime conditions and are higher than would be measured in the very early morning hours (3 A. M.).

Automobile Noise

Automobile traffic (exclusive of trucks and commercial vehicles) is the most common source of noise on the highways, although it is not the loudest. The following outlines some important results of the study concerning automobile traffic alone.

The average noise level due to autos was computed separately for each test site at each location. At every location and at all three distances from the highway, the average noise generated by autos was generally loudest during acceleration from a stop (intersection). The loudest average auto noise, as recorded on the C scale was 84 db at the 50-ft. test destance. At 300 ft. , the highest average was 73 db. It must be kept in mind that the loudest average noise does not mean the loudest single reading obtained, but rather, the loudest group of readings obtained at various test sites at the same distance from the highway and same type of freeway section (i. e. , cut, fill, intersection, etc.). The loudest single reading would be considerably greater than the average.

For all types of freeway sections, the average auto noise ranged from 75 db at 50 ft. to 69 db at 300 ft. , as measured on the C scale. B and A scale readings were on the average, 9 and 15 db lower than the C scale readings, respectively. In the over-all average for all distances at all locations, auto traffic noise was louder than the background level by 7 db on the A scale, and 5 db on the B and C scales.

At locations where the background level was high, many cases arose in which the noise generated by light auto traffic was not discernable from the background level, except at the 50 ft. distance (see Table 2). One incident arose in which the meter readings on auto traffic were lower than the average background level. This was due to the fact that background level measurements were taken at times when there was no traffic in the immediate vicinity of the test location, but with the possibility of heavy traffic at a distance. This condition occasionally caused higher meter readings than that due to a few slow moving autos in the test area. Such a condition may exist at an intersection when traffic is traveling in platoons between signals. Heavy traffic may be approaching the intersection from some distance away, or may be stopped at the intersection and there is traffic at a distance.

The tests showed that the difference between auto noise and background levels decreased with distance from the highway (see Table 2). This pattern appeared on all meter scales. The differences at any one type of freeway section were largest on the A scale, less on the B scale, and least on the C scale. This is to be expected because of the weighting networks

TABLE 2
DIFFERENCE BETWEEN AUTO NOISE AND BACKGROUND LEVEL

Test Distance feet	Type of Location	Average Decibels A Scale	B Scale	C Scale
50	1 Inclined	11	8	9
	2 Intersection	5	8	6
	3 Level (high speed)	11	10	7
	4 Elevated	8	6	5
	5 Cut	6	4	3
150	1. Inclined	10	4	9
	2. Intersection	7	7	3
	3. Level (high speed)	8	6	2
	4. Elevated	4	4	5
	5. Cut	5	6	7
300	1 Inclined	-	-	-
	2. Intersection	3	2	0
	3. Level (high speed)	6	2	7
	4. Elevated	4	3	2
	5 Cut	9	1	5

TABLE 3
NOISE LEVELS OF TRUCKS, AUTOS, AND BACKGROUND

Averages are given for each test distance and type of freeway section.

Section and Vehicle	Distance feet	Average Decibels A Scale	B Scale	C Scale
1. Inclined				
Trucks	50	73	79	86
Autos	50	61	67	78
Background	50	50	59	69
Trucks	150	66	76	80
Autos	150	54	61	67
Background	150	48	58	62
2. Intersection				
Trucks	50	77	84	91
Autos	50	64	75	84
Background	50	57	67	76
Trucks	150	66	77	84
Autos	150	58	71	79
Background	150	52	64	73
Trucks	300	62	70	78
Autos	300	57	67	73
Background	300	52	63	69
3. Level				
Trucks	50	69	79	83
Autos	50	59	66	72
Background	50	48	56	65
Trucks	150	65	72	77
Autos	150	54	62	73
Background	150	46	56	72
Trucks	300	53	60	71
Autos	300	47	53	69
Background	300	43	55	66
4. Elevated				
Trucks	50	60	70	80
Autos	50	55	59	66
Background	50	48	55	62
Trucks	150	58	66	72
Autos	150	54	58	67
Background	150	53	53	63
Trucks	300	55	60	70
Autos	300	54	58	66
Background	300	50	55	64
5. Cut				
Trucks	50	69	72	77
Autos	50	65	69	75
Background	50	59	65	72
Trucks	150	58	65	74
Autos	150	55	61	70
Background	150	52	60	68

TABLE 3 (Cont'd)

Section and Vehicle	Distance	Average Decibels A Scale	B Scale	C Scale
5. Cut (cont'd)				
Trucks	300	56	65	72
Autos	300	51	59	69
Background	300	46	58	64
Highest Average Truck Noise	50	77 (intersection)	84 (intersection)	91 (intersection)
	150	66 (intersection)	77 (intersection)	84 (intersection)
	300	62 (intersection)	70 (intersection)	78 (intersection)
Loudest Single Truck Noise	50	90 (intersection)	97 (intersection)	102 (intersection)
	150	81 (inclined)	88 (inclined and intersection)	93 (inclined intersection and level)
	300	77 (Elevated)	84 (Elevated)	87 (Elevated)
Over-all Average Truck Noise	50	70	77	83
	150	63	71	77
	300	57	64	73
Over-all Average Auto Noise	50	61	67	75
	150	55	63	71
	300	52	59	69

used in the instruments and is further substantiation of the known fact that the high frequencies are more rapidly attenuated than the lower frequencies. The largest differences occurred under conditions of (1) maximum power on an inclined freeway section, (2) acceleration from a stop at an intersection, and (3) high speed on a level freeway section.

Truck Noise

As was expected, trucks were found to be a more intense source of highway noise than autos (see Tables 3, 4, and 5). On an over-all average, the truck noise level was 6 db above that for autos. This figure is small and is due to the grouping of all trucks together, there being many more light trucks than heavy ones. The number of readings on the various types of vehicles comprising the test samples were reasonably proportional to the frequency with which each type of vehicle passed the test location. Since there were greater numbers of two-axle trucks than other types, more meter readings were taken on this type of truck. Due to the fact that the noise generated by these light trucks is, on the average, not much greater than that of an auto, the average of all trucks combined was reduced.

Average readings on each type of truck at various test distances and on various types of freeway sections may be found in Table 4. Average truck noise was found to exceed that of autos in all locations and at all distances (see Table 5). The difference between truck and auto noise at a single distance and location ranged from 1 to 13 db on the A scale, 1 to 14 db on the B scale, and 1 to 11 db on the C scale. The greatest difference occurred under the condition of maximum power on an inclined freeway section, where the average truck noise exceeded that of autos by 11 db on the A scale, 14 db on the B scale, and 10 db on the C scale. The least difference was noted on elevated freeway sections.

TABLE 4
NOISE LEVELS FOR VARIOUS TYPES OF TRUCKS

Averages for each distance and type of freeway section.

Type of Location	Test Distance feet	C Scale - Decibels (average) Light Gasoline-Powered Trucks	Heavy Gasoline-Powered Trucks	Diesel Trucks
1. Inclined	50	82	85	89
	150	73	79	82
2. Intersection	50	91	92	91
	150	82	82	86
	300	76	79	81
3. Level	50	78	85	89
	150	71	83	84
	300	73	74	76
4. Elevated	50	71	82	83
	150	70	76	79
	300	69	74	76
5. Cut	50	79	81	81
	150	72	71	74
	300	71	71	73

The loudest single truck noise was noted during acceleration from a stop at an intersection. The maximum noise registered on each of the three scales was as follows: C scale, 102 db; B scale, 97 db; A scale, 90 db. These readings were taken at a distance of 50 ft.

The average truck noise was computed for all trucks at each individual test site (see Table 3). The highest average was found to occur at an intersection under the condition of acceleration. The averages for the other conditions may be found in Tables 3, 4, and 5.

TABLE 5
AMOUNT BY WHICH AVERAGE TRUCK NOISE EXCEEDED AVERAGE AUTO NOISE

Difference between the averages of truck noise and auto noise for each distance and type of freeway section.

Type of Location	Test Distance feet	A Scale	Decibels B Scale	C Scale
1. Inclined	50	13	12	8
	150	11	14	10
2. Intersection	50	13	9	11
	150	7	6	4
	300	4	3	6
3. Level	50	9	7	10
	150	12	6	4
	300	5	4	1
4. Elevated	50	2	4	3
	150	2	4	3
	300	1	1	3
5. Cut	50	4	5	3
	150	3	4	4
	300	7	5	4

An analysis was made to determine the difference in decibel readings between the averages of light gasoline-powered two and three axle trucks, heavy gasoline-powered trucks, and diesel-powered trucks, at each distance and each location (see Table 5). Only the C scale readings were used. In general, the results show that heavy gasoline-powered trucks were noisier than light trucks. In some cases the heavy trucks were several times as noisy. The difference between heavy gasoline-powered trucks and diesel-powered trucks averaged about 2 db for all sites.

Part 2
Appraisal of Motor Vehicle Noise

Reference has been made in the introduction to the difficulties of measuring and evaluating motor vehicle noise due to the subjective nature of the phenomena. There have been repeated attempts to define loudness, annoyance, speech interference, and damage to hearing due to noise intensity. All of the definitions and degrees of objectionableness are of necessity subject to a range of values because of the vagaries of human judgement. It is possible, however, to made measurements of a physical quantity and corresponding judgements by observers which can then be compared by statistical methods to obtain a measure of the correlation between the quantities. Such a precedure has been used on a portion of the data collected in Part I and on subsequent data taken on vehicles operated on a chassis dynamometer. Before attempting to review the test procedure and results it is advisable to consider briefly the quantities used to measure sound.

The Decibel - What Is It?

There have been several references in the preceding material to the decibel, also called by its abbreviation, "db". Most people think that the decibel is uniquely associated with noise measurements, but actually it is a term borrowed from electrical engineering and represents a ratio of two quantities.

Since air-borne sound is a variation in atmospheric pressure, the pressure variations are used as the measure of the noise. The reference pressure is usually taken as the threshold of hearing for young ears and has been set at 0.0002 microbar. This is "0" decibels on the noise level scale.

Because of the great range of sound pressure and power, it is convenient in measurements and calculations (either electrical or accoustical) to express the ratio between any two amounts of power or pressure in units on a logarithmic scale. The decibel (1/10 of a bel) on the base-10 scale, is in almost universal use for this purpose. The number of decibels, N_{db}, corresponding to the ratio between two amounts of power, P_1 and P_2 is

$$N_{db} = 10 \log_{10} \frac{P_1}{P_2}$$

When the sound-pressure is known instead of the sound power, the equation for decibels becomes

$$N_{db} = 20 \log_{10} \frac{\text{Sound Pressure (in microbars)}}{0.0002}$$

The equation using sound-pressure has the same form as the power equation, but the multiplier changes from 10 to 20 because the power is proportional to the square of the pressure.

Because of the logarithmic definition of the decibel it is not possible to add db's directly.

In order to combine two sounds it is necessary to know either the accoustic power or the sound pressure with respect to a common reference. These quantities can then be added and the resulting number of decibels computed. For example, if one sound has twice the power of another, then

$$N_{db} = 10 \log_{10} \frac{2}{1} = 10 \times 0.301 = 3.0 \text{ db}$$

So if two sounds are equal when measured in terms of accoustic power (or db), their sum will be 3.0 db higher than either one. For example: Two trucks each produce 90 db at a particular point. The two trucks together will develop 93 db.

Check: For each truck $90 = 10 \log \frac{P_1}{P_{ref}}$:

$$\text{so } \frac{P_1}{P_{ref}} = \text{anti log } \frac{90}{10} = 10^9$$

Adding the two power ratios gives

Truck No. 1 + Truck No. 2 =

Power ratio of $10^9 + 10^9$

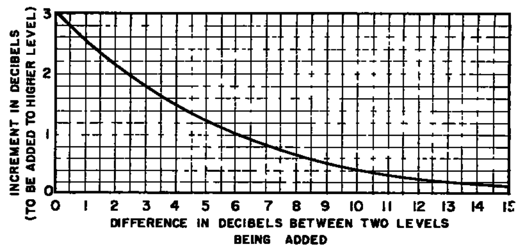

Figure 5. Chart for combining noise levels.

$$\text{Total db} = 10 \log_{10} 2 \times 10^9 = 90 + 10 \log 2.0$$
$$= 90 + 3.0$$
$$= 93 \text{ db}$$

Instead of going through the calculations as indicated it is simpler to use a chart giving the number of db to be added to the most intense sound when several sounds are combined. The curve of Figure 5 gives the data for combining noise levels.

Loudness - Phons

The loudness of a sound or noise is a subjective quantity and relates to the individual's appraisal of the sound power. One generally accepted definition of a physical method of specifying loudness is as follows: The loudness level of any pure tone is given by the intensity level of a 1000-cycle-per-second tone which sounds equally loud

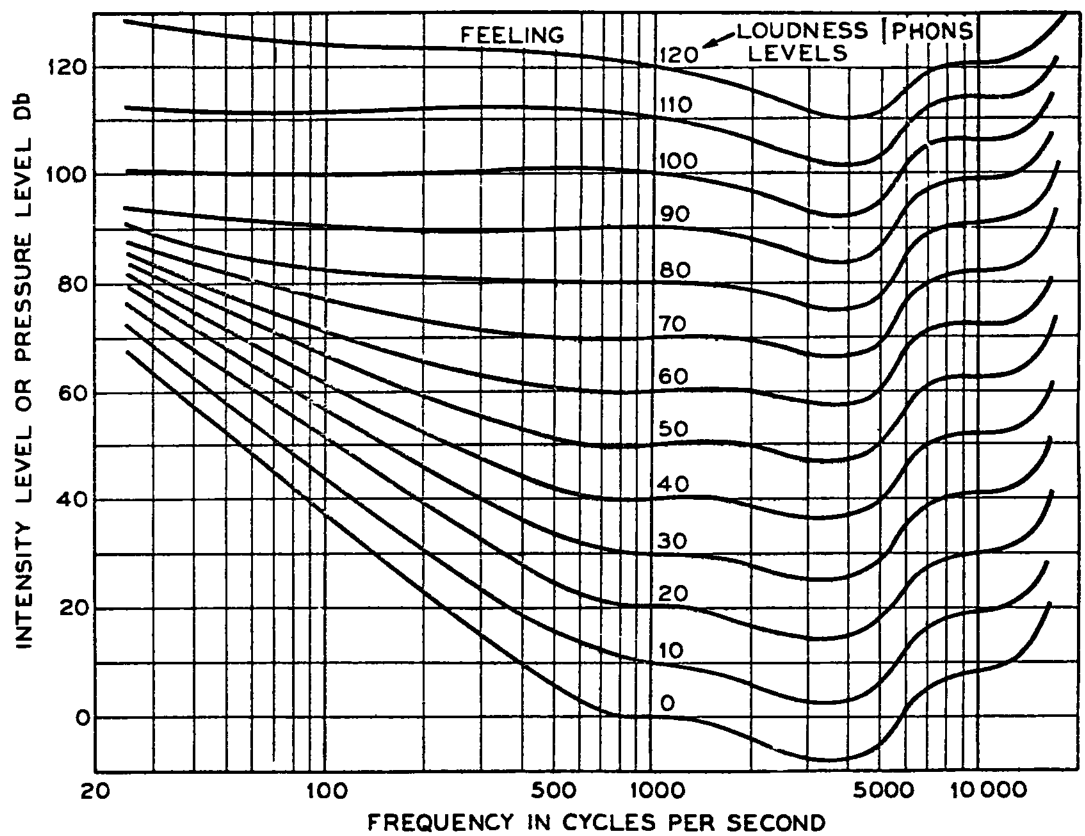

Figure 6. Equal loudness contours of pure tones (Fletcher-Munson curves).

when compared by an average human ear. For complex tones the loudness level is equal to the sum of the intensity levels of the 1000-cycle equivalents of all the components. The addition is not the arithmetic sum but is obtained by combining the accoustic power due to each component and evaluating the total power in decibels as explained in the foregoing section. The intensity level of the reference tone is reported in phons. Figure 6 gives the data relating loudness level in phons to intensity level in decibels.

The subjective loudness, or the degree to which a complex sound affects a person, is not the same as the loudness level defined above because the human ear adds the components in a different manner. To obtain the subjective loudness, in phons, of a complex sound it is necessary to compare it directly with a 1000-cycle tone. The comparison must be made many times by each of several observers and the results averaged. This is evidently not a suitable method for measuring the noise of a passing truck.

Loudness - Sones

We do know and we frequently remark that some sounds are louder than others. How much louder? Well perhaps twice as loud or three times as loud, we may estimate. This type of appraisal is entirely subjective. This is the field of the psychologist. Such judgment or sensation evaluations defy measurement directly, but the psychologists have found that when people are asked to make judgments of the loudness of noise (complex sounds) they are quite consistent in stating when one noise is twice, three times, or one-half as loud as another. Thus a scale of loudness which rank-orders sounds from "soft" to "loud" has been devised. The units of this scale are sones.

The physical quantity that has been measured simultaneously is the sound-pressure level in decibels. As a reference, a sound-pressure level of 40 db (40 phons) relative to 0. 0002 microbar for a 1000-cycle tone is taken as 1 sone. A tone that sounds twice as loud is 2 sones. A chart relating the sound-pressure level of a 1000-cycle tone and the corresponding number of sones is given in Figure 7. Also shown is the relation for a particular wide-band noise (sort of a hishing sound). To get the combined loudness of two or more noises in sones, one can add directly the value of sones for each noise. Thus, the total loudness of three noises of 15, 18, and 30 sones is 63 sones.

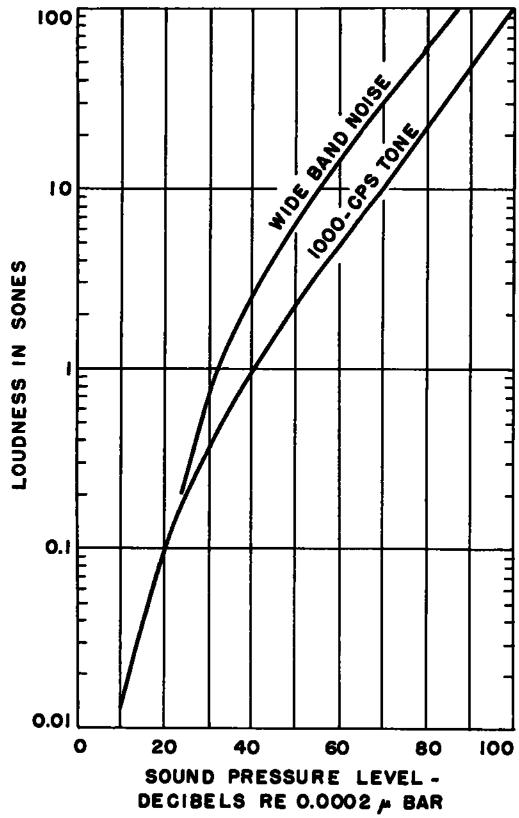

Figure 7. Loudness versus sound-pressure level for wide-band random noise and a pure tone.

Sound Level Meters and the Human Ear

The sound level meter approved by the American Standards Association (ASA) for measuring noise level does as good a job in measuring loudness as does any single commercial instrument on the market, but it is not entirely adequate in itself. It contains electrical networks which make its sensitivity for a pure tone of each frequency quite similar to that of the average human ear at a given adaptation level. The theory of this sound level meter as a means of measuring loudness is based on two assumptions: (1) The loudness of a pure tone is not affected by the presence of other tones, and (2) Tones of different frequency add in the same way as do tones of the same frequency.

The functioning of the human ear makes these assumptions invalid for certain types of sound. The ear drum reacts to sound pressure in much the same way that a microphone diaphragm does. A linkage of small bones conducts the motion to an inner diaphragm to which is attached the basilar membrane. This membrane runs down the center of a tapered duct which is coiled like a snail. The endings of the auditory nerves are distributed along the basilar membrane. The nerves at any particular position are used to hear sounds of a particular frequency, but their frequency response is rather broad. Each nerve ending therefore can detect sounds in a considerable range of frequencies. The electrical potentials produced by the nerves when the ear is stimulated are proportional to the sound pressure up to a certain degree and thereafter show distortion of increasing degree. In addition to exciting some particular nerves more strongly, a loud tone will excite the nerves in a longer section of the basilar membrane. If one tone partly saturates the nerve response in a section of the basilar membrane the ear will be less sensitive to other sounds which excite some of the nerves in this section. The result is that two simultaneous tones loud enough to cause some saturation will not be as loud if they are of almost the same frequency as they will be if they are far apart on the frequency scale. This phenomenon is called masking, and it is something which the ASA sound level meter does not take into account.

The fact that the ear distorts the sound before it reaches the auditory nerves also has a considerable effect on our hearing of some kinds of sounds, for it results in the introduction of subjective harmonics. If the external sound also contains harmonics these may interfere either constructively or destructively with the subjective harmonics. This again is something which a sound level meter cannot readily evaluate, especially since very little is known about this effect.

It seems then that the loudness of a tone is affected by the presence of other tones, that tones of different frequency do not add in the same way as do tones of the same frequency, and that in fact we do not know just how the components of a complex sound are added in the human ear.

Yet it is known that for many kinds of sound, whether simple or complex, the ASA sound level meter readings can be converted to loudness values with a fair degree of accuracy. The important question to consider here is whether or not this is true for truck noises. The largest discrepancies between subjective loudness and meter readings have been found in cases where there were important sound components below 300 cps and where the sounds were predominantly of a harmonic nature. Unfortunately, truck sounds, as shown by our analyses, are largely harmonic and do have important components below 300 cps.

A recent study of the truck noise problem has been made by the Armour Institute in Chicago (21) in which a technique of analysis using octave bands of frequencies has been used. With this technique the total noise is first recorded on a magnetic tape. The tape is then evaluated in terms of the sound-pressure level in each of eight bands. These components are then converted into sones using the curves of Figure 8 and the total loudness in sones is determined by adding the individual values for each band. It is claimed that the results of this technique correlate well with jury ratings of the noises.

Even after we have measured loudness we are faced with another problem: What is the relationship between loudness and objectionableness or degree of annoyance? These are highly subjective quantities which are difficult, if not impossible, to evaluate. The important thing to know now is whether or not the correlation is close enough so that we can be satisfied that a loudness reduction will bring the desired improvement in human living conditions. We need to learn just what factors other than loudness contribute to annoyance caused by noise.

It has been found that high frequencies are intrinsically more annoying than low and that the least objectionable tones lie between 256 and 1040 cps. For high intensities the change in annoyance with frequency is more pronounced than for low intensities.

Because of differences in design, there are large differences in the frequency components present in the noises from different trucks. Since it takes a shorter chamber to muffle a high frequency than it does a low one, it is possible for a conventional muf-

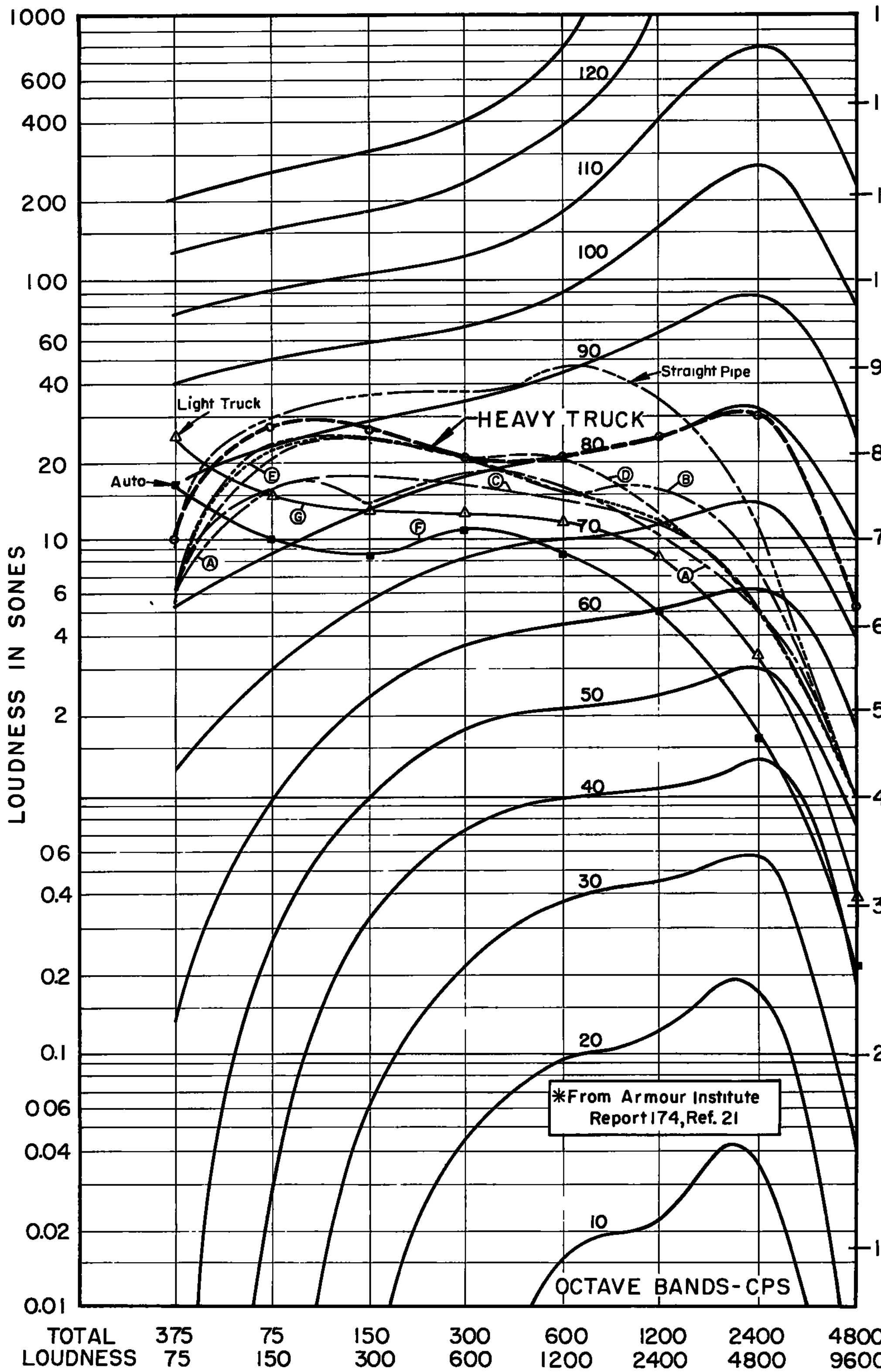

Figure 8. Conversion chart - Db to sones.

fler to do a satisfactory job at frequencies above 300 cps but the same muffler may be quite unsatisfactory for the lower frequencies. At the latest testing sessions of the California Motor Transport Associations, Inc. (6) most of the mufflers tested were very effective at frequencies over 300 cps, though several were quite unsatisfactory.

Large variations of frequency also arise from the operation of the truck at various speeds and with various gear ratios. Probably the most bothersome noises come from trucks when the high engine speeds reached just before shifting create a noise of particularly high intensity and high frequency.

When a truck is accelerating and changing gears there are three factors greatly affecting the annoyance: (1) greater sound intensities are generally reached under these conditions than under other modes of operation, (2) the sounds are of higher frequency than normal, and (3) there is great variation in the loudness level. This variation in the loudness level may account for a considerable part of the annoyance value, for it is known that intermittent sounds are more annoying than steady sounds of the same intensity.

Since our basic aim is to reduce the annoyance caused by highway traffic the factors which materially affect the amount of annoyance certainly need to be considered in any broad view of the problem. But, except for loudness, these factors are all so variable with persons and circumstances that it is difficult to see how they could have any place in legal definitions or law enforcement practices. While one person may prefer high-pitched noise and another one low, and one person may prefer a steady noise and another a varying noise, it is safe to assume that, for highway noise at least, the annoyance increases with loudness, both in its effect on each person and in the number of persons affected. If we assume a uniform distribution of population adjacent to a highway, noise twice as loud will be heard by four times as many people.

EVALUATION PROCEDURE

The tape recordings made during the field tests of Part I were reviewed. As noted previously, there were quite a number of runs in which either the calibration voltage or frequency was not stable; therefore these were not used. Out of several hundred tapes, a group of 23 were selected covering the complete range of automotive noises including a quiet automobile, a very noisy truck, a truck with a straight pipe exhaust

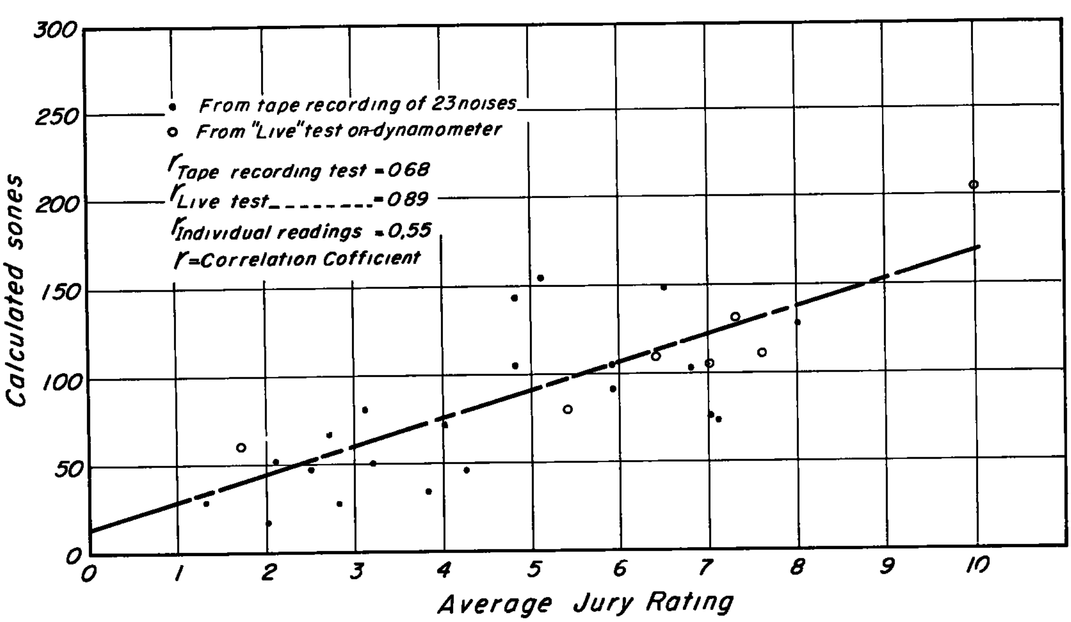

Figure 9. Calculated sone values versus average jury ratings.

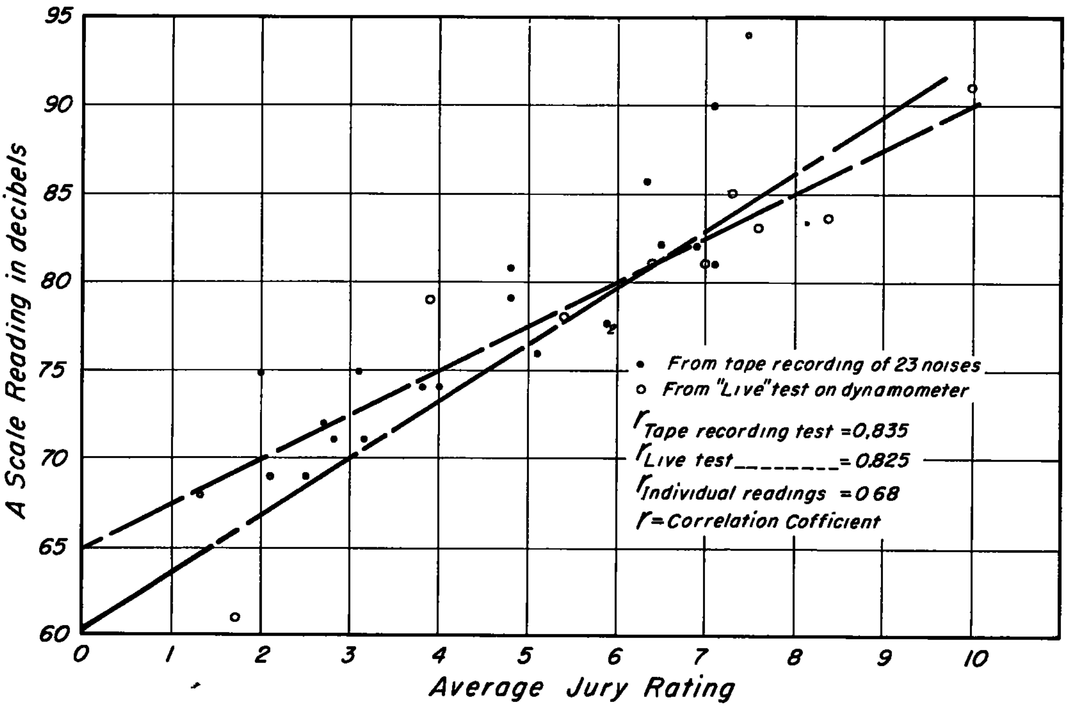

Figure 10. A-scale readings versus average jury ratings.

and a jet airplane.

Each tape was carefully analysed using the sone (octave band) analysis method, and with the A and C scales of the ASA meter.

The individual tapes were assembled into a reel with an introductory statement and an explanation of the appraisal system. The instructions given were as follows: "You are asked to listen to the noise produced by trucks and passenger vehicles of various kinds and operated with different engines, mufflers, speeds and loads and to evaluate their noise on a relative scale. The scale runs from 1 to 10, where 1 is to be considered very inoffensive and 10 is to be considered very annoying to the extent of being irritating or painful. A midscale value of 6 will be considered as the borderline between acceptable and unacceptable.

"The basis of rating is to objectionableness, rather than loudness. We are particularly interested in the annoyance aspect. You may find that some noises are more annoying even though they are no louder than others.

"The rating is to be made from a point approximately 50 feet from the edge of the roadway in the general area of the microphones."

The reel of automotive noises has been run for a number of observers, including a group of approximately 65 people participating in a public hearing of the motor vehicle noise problem on November 10, 1954, at the Institute of Transportation and Traffic Engineering, University of California, Berkeley, California. Each observer was requested to rate the noises in accordance with the above instructions.

In addition to the reel of automotive noises recorded on the magnetic tape a series of "live" tests were conducted during the November 10 public hearing. The noise tests were conducted on the chassis dynamometer at the Engineering Field Station of the University of California at Richmond, California. Five types of vehicles were used, including a passenger car, a pick-up truck, a gasoline powered city delivery truck, a gasoline powered city bus and a diesel powered 200 hp heavy duty truck tractor. All were operated at maximum power output at a road speed of 40-45 mph on the dynamometer.

The truck tractor was operated with five different commercial mufflers and a straight pipe.

The jury was assembled approximately 50 feet away from the vehicle on the dynamometer. Except for a few muffler manufacturers in the jury, the people were not aware of the details of the exhaust systems and were as unbiased and heterogeneous as could be obtained in a group of 65 individuals.

APPRAISAL RESULTS

The results of the appraisals of the magnetic tape recordings and the live tests have been analyzed statistically to determine the relationships, if any, between the jury ratings and the meter readings. In order to compare several methods of measuring the noise of motor vehicles, three sets of data are presented: (1) A plot of the average jury ratings vs. the "sone rating" for both the tape recordings and the "live" tests; (2) the jury ratings vs. the "A-scale ratings" for the same conditions; and (3) the jury ratings vs. the "C-scale ratings" for the same conditions.

The average jury rating for each test condition is shown plotted on the scatter diagrams of Figures 9, 10, and 11. The regression line and the correlation coefficient for each set of conditions are shown. In addition the correlation coefficient for the individual jury appraisals has also been computed and is shown on the corresponding figure.

A correlation coefficient of 1.0 would indicate complete and exact correspondence between jury rating and meter rating. Similarly a coefficient of 0.0 would indicate no relationship. A value greater than 0.5 indicates better than a chance relationship and begins to have significance. Since it is not possible ever to obtain a coefficient of 1.0 it will be necessary to select a value that will be reasonably acceptable. It would seem that a correlation coefficient of 0.80 would be satisfactory for establishing the relationship between jury appraisals and motor vehicle noises.

The data on Figure 9 for the "sone-rating method" show that the same regression line fits both the data for the magnetic tape and the "live" tests. The correlation coefficient for the average jury appraisal vs. the "sone-rating" is 0.89 for the "live" tests and 0.68 for the magnetic tape data. If each individual rating is used instead of

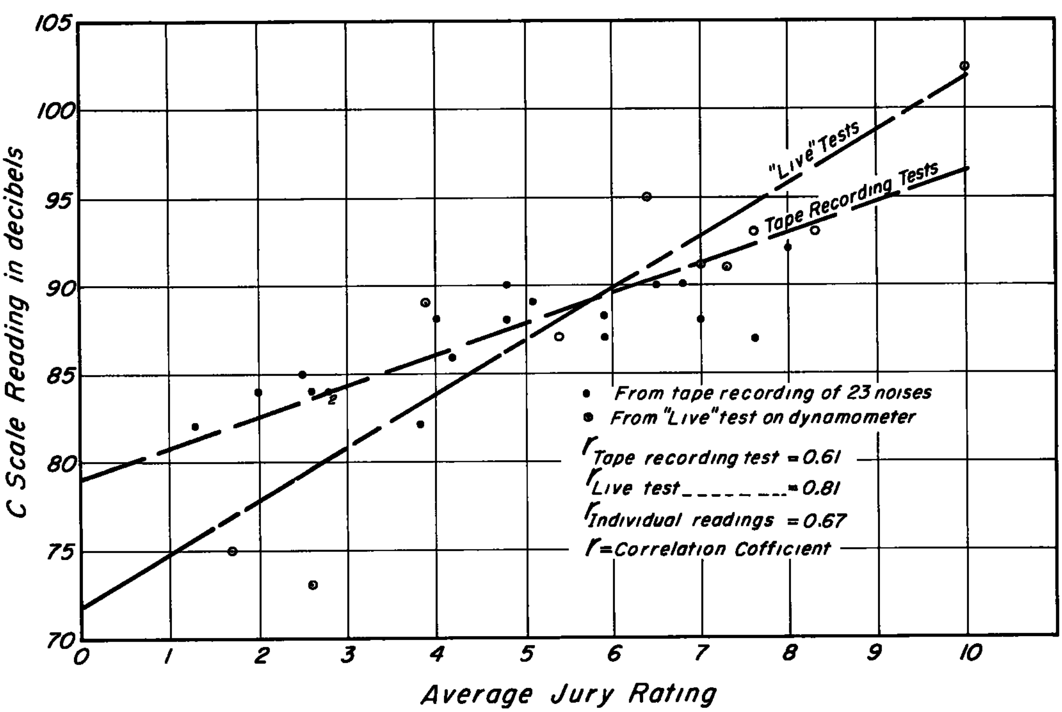

Figure 11. C-scale readings versus average jury ratings.

the average for the jury the correlation coefficient for the magnetic tape data drops to 0.55.

The "A-scale rating method" data are shown in Figure 10. The regression lines for the magnetic tape and "live" tests are not exactly the same, but have approximately the same slope. The correlation coefficients are shown to be 0.835 and 0.825 for the magnetic tape and "live" data respectively for the average jury ratings. The correlation coefficient for the individual jury ratings is 0.68.

The "C-scale rating method" data are given in Figure 11. These data show substantially different regression lines and correlation coefficients for the average jury ratings. The values are 0.61 for the magnetic tape data and 0.81 for the "live" data. For the individual jury appraisals the correlation coefficient is 0.67.

DISCUSSION OF JURY APPRAISALS

The above data show that both the "sone-rating method" and the "A-scale rating method" give correlation coefficients above 0.80 for the average jury ratings. The values are sufficiently high to be useful in measuring motor vehicle noises. The "C-scale" correlation is not high enough to be useful in evaluation techniques. This conclusion is substantiated by other references given in the bibliography.

The correlations based upon the individual jury appraisals are lower in all cases than when the average jury ratings are used. This is to be expected because of the wide range of subjective interpretations given to each noise by the various individuals. Taken as a group of individuals the correlation has to consider a much broader range of values to include each and every appraisal than when the weighted average of the group is used for each noise condition. Even if the individual readings are considered the correlation has statistical significance but not as much as when the average jury rating is used.

For purposes of analysis the sone-rating method yields more information than the A-scale method because of the 8-band spectral breakdown. It is possible with the sone method to determine in a broad sense the frequency distribution of the noise source. On the other hand, the sone method is not readily portable and cannot be used for field work except by making a tape recording and subsequently performing a laboratory analysis.

The A-scale method has distinct advantages as a field enforcement instrument and the equipment is readily portable. It has been shown that it yields correlation coefficients comparable to the sone method and should therefore be equally acceptable as an over-all single reading instrument to use as a means for determining compliance with an acceptance specification.

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Second Report of Special Task Committee on Roadside Design to Reduce Traffic Noise, Dust, and Fumes

WILBUR H. SIMONSON, Chairman, Chief, Roadside Section
Bureau of Public Roads

The first report of this committee summarized the 1953 study on what we know, what we do not know, and what research is needed for "Abatement of Highway Noise with Special Reference to Roadside Design."

Part 1 of this 1954 study (second report) outlines ways and means to obtain answers to unknowns on reduction of traffic noise on major highways. Methods, equipment, and units of measurement are reviewed for guidance in field tests initiated to measure and evaluate types of buffer planting and other methods of abatement. Comparative field tests are needed to assist the highway engineer in abating traffic noise that is objectionable to roadside dwellers.

Part 2 of this report presents information available to date regarding traffic fumes on major highways.

Part 1
Reduction of Noise

● ABATEMENT of highway traffic noise requires a sympathetic but critical approach. What are the possibilities of midjudging this factor in the planning, design, and development of new highways and expressways? Is the main question the fact that loud noise sources may be introduced in a quiet residential area? Does the location of heavy traffic in a residential neighborhood have any effect on the value and use of property abutting major highways by reason of the noise factor? What methods of measurement should the highway engineer use to determine the most effective and economical means for abating highway noise to abutters?

Research is needed to find answers to these questions. A forward step toward the development of standards for reduction of noise at the vehicle source was the adoption of a specification for muffler design early in 1954 to establish a maximum permissible noise level and an agreed method of measuring truck exhaust noise.

BERANEK-ARMOUR-ATA METHOD OF NOISE MEASUREMENT IN SONES (EQUIVALENT-TONE)

On March 3, 1954, the Automobile Manufacturers Association Motor Truck Committee announced in a press release that they had adopted the Armour method of truck noise measurement sponsored by the American Trucking Associations as a gauge by which they were going to establish a specification of maximum noise level which no truck would exceed when it comes off the assembly line. This action was taken on the advice of its Truck Noise Subcommittee. David C. Apps, chairman, is head of the Noise and Vibration Laboratory at General Motors Proving Ground. A brochure was prepared by the AMA Motor Truck Committee to explain evaluation of truck noise by the Beranek-Armour-ATA method, described in the press release as follows:

"A major advantage of the (Armour) method, ... is its use of commercially available instruments. These include a high-quality tape recorder and microphone, a set of octave filters, and means for acoustical calibration.

"The proposed (specification for muffler design and performance) calls for a maximum noise level of 125 sones,[1] with the sones measured in each of eight bands covering

[1] "The sone is an arithmetic unit rather than a logarithmic unit, like the decibel, so that a sound of 175 sones is about seven times as loud as one of 25 sones. This type of representation seems to be advantageous in comparing test measurements with results in pyschological tests and is an easier concept than a logarithmic unit for the layman to understand." (SAE Transactions, Volume 62, 1954, p 152, "Measurement and Evaluation of Exhaust Noise of Over-the-Road Trucks," by D. B Callaway)

the frequency ranges form 37 to 9,600 cycles per second, then added to produce the total of 125 or less.

"The AMA committee pointed out that truck manufacturers have made significant advances in muffler design in recent years, but expressed a belief that adoption now of a standard method of measuring results would help stimulate further progress. At the same time, the committee emphasized that other promising methods of noise measurement may, when thoroughly tested, provide an even better standard. Such possibilities will not be overlooked, it said."

What this means in terms of quieting trucks was explained by Lewis C. Kibbee, Chief of the Equipment and Operations Section, American Trucking Associations, before the Kiwanis Club of Akron, Ohio, on April 22, 1954, in his address: ". . . we have roughly taken the noise spread of over-the-road trucks and cut it in half, and we won't have any more of them in the upper half. . . . The trucks that bother people . . . are the ones loud enough to stop conversation, rattle the dishes, and wake the baby. . . . Only about 25 percent of the trucks are in this class even in the West and only five percent here in the East."(7)

TABLE 1[a]
LOUDNESS OF PASSENGER AUTOMOBILES
(At Speeds of 50-60 mph)

Observations made on passenger cars	Relative loudness in sones calculated from octave band levels		
Distance from source on highway pavement (feet)	Maximum loudness approximately (sones)	Average loudness approximately (sones)	Minimum loudness approximately (sones)
30	75	35	22
300	12	6	3
1,000	4	2	1

[a] Table 1 is adapted from Report No. 1, "Noise and Vibration Problems Associated with Traffic on Edens Expressway," Prepared by Armour Research Foundation of Illinois Institute of Technology for the Cook County Highway Department, Chicago, Illinois, April 30, 1952.

The loudness of passenger automobiles reported in Table 1 was not objectionable to residents along the Edens Expressway in Chicago. Observations were made on passenger cars operating at 30 feet and at usual speeds of 50-60 mph. These were made to facilitate comparison with truck and background noises. The report stated that the background noise was five sones for a typical location about 700 feet from the Expressway in the daytime. It can readily be seen from Table 1 above that the average automobile at 300 ft. was just audible, since the average loudness approximating six sones was about the same as the background level of five sones for the typical suburban residential location just mentioned. Table 1 in the 1953 study, however, shows that the city of Chicago traffic backgound noise is of much higher loudness than the average for residential area background noise measured along the Edens Expressway. It shows also that industrial area noise averaged about two times city residential area noise and that background traffic noise in the city of Chicago was relatively louder than industrial area noise.

WIDE-BAND MEASUREMENTS AND EVALUATION OF LOUDNESS IN SONES

During 1954, there was increasing recognition of the need for a "yardstick" to measure and evaluate noise in correlation with the human ear. Table 2 compares three reports on test procedures. A brief description of the use of octave band levels and computation of loudness is given in the April 30, 1952 Research Report No. 1. It is pertinent to point out that the sound level meter indicates sound pressure level without regard to frequency distribution of the sound energy. For this reason, it is first necessary to determine distribution of sound energy with frequency, and then to weight properly the various frequency contributions. These steps are necessary in order to correlate measurement of the physical property of a noise with subjective ear judgments of loudness by individuals. Recent developments and techniques have made possible the calculation of loudness in sones from sound pressure levels in relatively narrow bands of frequencies. The sone is an arithmetic unit such that a loudness of 100 sones sounds twice as loud as one of 50 sones, and 25 sones sound about one half as loud as 50 sones. This comparable unit of measurement was also used in the AMA Research Report No. 2 of January 6, 1954, as indicated in Table 2.

A comparison of the test procedures used in the following three research reports is attempted in Table 2: (1) April 30, 1952, Armour Research Foundation Report No. 1, "Noise and Vibration Problems Associated with Traffic on the Edens Expressway" for the Cook County Highway Department, Chicago, Illinois. (2) January 6, 1954, Automobile Manufacturers Association Report on the "Beranek-Armour-ATA Method of Measuring Truck Noise (Equivalent-tone)," prepared by the AMA Truck Noise Subcommittee, David C. Apps, Chairman Detroit, Michigan. (3) February 1954, Institute of Transportation and Traffic Engineering, University of California, Research Report No. 15, including Appendix 15-A, "Noise Measurements on Expressway-Type Facilities," by Finch and Partridge.

The AMA report of January 6, 1954, (Research Report No. 2 Table 2) describes the equivalent-tone method for determining the loudness of sounds. It is stated that this improved method of rating combines the basic relations of sound intensity, frequency, and ear response, yielding accuracies which are considered adequate from an engineering standpoint. The calculated loudness for most types of noise agrees with individual ear judgments while the overall sound level given by the sound level meter usually does not agree with ear judgments. The February 1954 Research Report No. 3 of the Institute of Transportation and Traffic Engineering, University of California, indicates that

TABLE 2

COMPARISON OF THREE REPORTED TESTING PROCEDURES DESCRIBED

	Research Report No. 1. April 30, 1952	Research Report No 2. Jan. 6, 1954	Research Report No. 3 Feb. 1954
Methods (Distances from Source)	Feet from edge of pavement 30 300 1,000 Loudness of traffic noises obtained by: Measuring sound pressure levels in octave bands. Determining loudness value in sones for each octave band Adding loudness contribution of all octave bands to obtain the total loudness in sones.	Microphone located 5 feet above ground and 50 feet from center of traffic lane used by the vehicle Where this distance cannot be obtained, use the inverse square law for correction for working distance between 30 and 80 feet.	Feet from center line of nearest traffic lane 50 150 300 A graph of the amplitudes of the frequency components was obtained by means of a logarithmic expander and a recording device manufactured by Sound Apparatus Company
Equipment[a]	1. Microphone 2. General Radio Type 759-B Sound Level Meter 3. Recording on magnitic tape Magnecorder Co. Type PT-6JA Unit 4. General Radio Type 1550-A Octave Band Analyzer	1 Microphone 2 A set of octave filters which incorporates a decibel meter and calibrated attenuator 3 A high quality magnetic tape recorder and microphone. 4. A means for accoustical calibration	1 Microphone[b] 2. Three General Radio Co. Sound Level Meters, Type 759-B 3. Recordings on modified Magnecord Amplifier, Model PT6-J. 4. Magnecord Magnetic Tape Recorder, Model PT6-AH. 5. General Radio Co. Sound Analyzer, Model 760, and Sound Level Meter Calibrator, Type 1552-A.
Units of Measurement	Sone (DB levels in octave bands plotted on special graph paper and the loudness computed.)	Sone (Maximum reading on the db meter recorded and the equivalent loudness in sones added to give a single combined reading for the loudness of the truck in sones.)	DB (Decibel) A Scale B Scale C Scale (To simulate to some degree the response of the human ear at the various portions of the frequency spectrum and noise levels

[a] Equipment meeting the standards of the American Standards Association manufactured by. General Electric Company, General Radio Company, Hermon Hosmer Scott, Inc., Western Electric Company, and others.
[b] Equipment described in detail in Appendix A, with complete list in Appendix E. (Feb. 1954 Research Report No. 3)

Figure 1. Planting of highway borders reduces annoyance of traffic to abutters. Liberal 75-ft. width between pavement and frontage road allows ample space for effective buffer planting.

simultaneous readings were made on all three A, -B, -C meter scales to simulate to some degree the human ear response at the various portions of the frequency spectrum and noise levels. Jury appraisals of industrial noises and noises such as these indicate that persons with normal hearing agree reasonably well in evaluating loudness.

The April 30, 1952 Armour Research Report No. 1 points out that this agreement should be interpreted as being within a reasonable range of possibly plus or minus 15 percent. The value of 100 sones should be understood as 100 sones plus or minus 15, thus representing a possible range from 85 to 115 sones, approximating the human tolerance factor in the evaluation of noise.

FIELD TESTS NEEDED FOR EVALUATION OF HIGHWAY NOISE ABATEMENT METHODS

Various methods of reducing traffic noise to abutters have been reported, but specific test measurements are not available. A number of field tests are needed to evaluate the effectiveness of barriers such as walls, embankments, and buffer-planting to abate noise. Uniform test procedures and units of measurement are suggested to simplify comparison of field tests set up for this purpose.

Identical noise sources should be used at highway locations with existing barriers or types of buffer-planting and at similar locations without any barrier or buffer-planting to muffle traffic noise. The effectiveness of the barrier or buffer-planting may be determined in each test by recording the loudness of noise with, and without, a barrier or buffer-planting. Differences would then indicate the effect of the barrier or buffer-planting. Tests would be more satisfactory if done when traffic is light and background noise is not excessive.

In discussing suggested future work, Finch and Partridge urge that an evaluation be made of the effect of various barriers or types of buffer-plantings to muffle traffic noise. Quoting from page 21 of Research Report No. 15, "Noise Measurement on Expressway-Type Facilities:

"The attenuation due to screening is important. Knowing the effect of various heights of and types of screens, several standard types could be designed, and the proper one to be used in any specified case could be determined by balancing the improvement due to its use against cost estimates, as is done in other engineering design work. Screening is perhaps one of the most important solutions to reducing the noise on existing freeways. . . .

"Existing background levels in various sections of a city and of cities and towns of

Figure 2. Frontage roads along this controlled-access highway increase the setback of buildings. Increased setback, together with a narrow buffer planting, reduces traffic annoyance to abutters.

different sizes should be investigated as a basis for determining the effect a freeway would have upon the noise levels of these locations. This work would provide information regarding existing levels near schools, churches, libraries, and the like. The necessary distance between freeways and these locations, or the screening necessary to allow the freeway to pass at a lesser distance could be approximated from such data, assuming that the level be nearly the same as before, or increased to a level which is not deleterious to study or meditation."

CONDITIONS FOR ROADSIDE TESTS TO DETERMINE EFFECTIVENESS IN ABATING NOISE

1. Open highway section without trees or buildings; level, raised, or depressed.
2. Highway section with retaining walls; face of wall bare, and face of wall covered with heavy growth of vines: without any planting above and with planting above.
3. Highway section with buffer-planting; narrow-type, basic-type, and wide-type.

Barriers such as walls and embankments, as well as types of buffer-planting are briefly described and illustrated in the 1953 report.

CONCLUSION

1. Before 1952, little was published on the subject of highway noise. Noise investigators directed their attention mainly to industrial noise until 1952 when the Armour Research Foundation Report, "Noise Problems Associated with Traffic on the Edens Express," (No. 1 in Table 2) was prepared for the Cook County Highway Department, Chicago, Illinois.

2. The 1953 study-survey (First Report by this committee) brought out the fact that, with few exceptions, published data were primarily concerned with industrial noise problems and measurement thereof in decibels, a unit of measurement not always in good correlation with the human ear.

3. This 1954 study (Second Report), with selected references published during 1954, appended, is evidence not only of a broader interest and greatly accelerated progress in noise abatement, but also of increased emphasis on the need for better correlation of noise measurements with jury judgments. The layman finds it easier to understand and comprehend the relative measurement and evaluation of loudness in terms of the human ear, when the sone, an arithmetic unit of loudness measurement, is used instead of the decibel, a logarithmic unit of sound pressure or energy level measurement. The use of the sone seems advantageous in comparing test measurements for different methods of abatement with results of psychological roadside tests, being more easily understood by the average person than use of the decibel, a logarithmic unit.

4. During 1955, the committee recommends the initiation of field tests to measure and evaluate noise abatement methods for reporting in January, 1956, at the next annual meeting.

5. Early in 1956, reports from field tests on practical ways and means of abating highway noise will be of timely value in forthcoming large-scale programs in the United States (Interstate highways, expressways, turnpikes, etc.). Planning of such arterial routes near developed residential communities or through potential neighborhood areas should aim to keep traffic annoyance to abutters to a minimum by:

A. Care in Location. In the consideration of location, the matter of noise is one of the elements in the planning of routes with heavy traffic volumes in the vicinity of residential areas.

B. Adjustments in Highway Design. Adequate right-of-way widths to keep buildings at a greater distance from the traveled way and thereby effect a reduction of traffic annoyance to abutters.

C. Noise Abatement Methods. Adequate barriers and buffer-plantings installed at selected critical locations only (not continuously), such as: (1) erection of barrier structures, walls, embankments, and other structures; (2) installation of buffer-plantings, hedges, trees and shrubs, vines, as outlined in the 1953 study (first report): (a) narrow-type buffer-planting, (b) basic-type buffer-planting, and (c) wide-type buffer-planting; (3) combinations of barriers and buffer-plantings as necessary in special situations.

6. Future Research. In regions where snow is a factor, both the beneficial and the adverse effects of structural barriers and various types of buffer-planting should be weighed.

REFERENCES PUBLISHED DURING 1954 STUDY
(To Supplement Selected References in 1953 Study — with Comments Pertaining to Abatement of Highway Noise.)

1. "Noise May Cause Accidents," A. J. White, Director of Motor Vehicle Research, South Lee, N.Y. November, 1954. Press Release (Univ. of N.H.). — "Noise may be a contributing factor to commercial motor vehicle accidents." This and other facts were revealed at a lecture by A. J. White, Director of Motor Vehicle Research of South Lee, New Hampshire.

Addressing a group of engineers representing insurance companies at the University of New Hampshire, Mr. White pointed out that interior cab noises of certain frequencies may cause fatigue, irritation and predispose truck drivers to become involved in accidents.

"Noise is a contributing factor to accidents if it is of an annoying type," stated Mr. White.

"Acoustical engineering is vital to protect truck drivers against noise values that cause fatigue and strain. A truck operator should be considered in the acoustical design of the operating cab of the vehicle if safety is to be of prime importance.

"The noise or sound level of present commercial vehicle cabs is too high for safety. Repeated exposure merely means tolerance of high noise levels and not elimination of the fatigue factor. Further research in this field is essential," said Mr. White.

"A driver who pilots a large truck and trailer assembly for eight hours should be considered from an acoustical angle because constant noise saps his energy and probably decreases his reaction time."

2. "Easy on the Ears," Sound Barriers of Trees and Shrubs Muffle the Cacophony, The New York Times, Sunday October 10, 1954. By P. J. McKenna. — This illustrated article points up the fact that "Noise is one of the most troublesome by-products of our modern age. In particular, noise resulting from motor vehicle traffic." The use of plants as insulting material to reduce the noise around homes is discussed by P. J. McKenna. "The principle . . . recognized . . . that materials used in noise reduction must be placed near the source of the noise. . . ."

3. "Auto Noises on Way Out," David C. Apps, Head of the Noise and Vibration Laboratory at General Motors Proving Grounds, Milford, Mich. From "The Oregonian," October 23, 1954. — "Chicago (AP) - A noise expert . . . predicted automobile engines will be so quiet that motorists will have to check the oil pressure gauge to tell whether they are running. The day of virtually noiseless engines was described at a national noise abatement symposium by David C. Apps, head of the noise and vibration laboratory at General Motors Proving Grounds, Milforn, Mich. — "Apps told some 300 engineers that modern techniques such as acoustical blankets and firewall treatment, can make engines vartually silent.

"To cut down on other traffic noises produced by automobiles - such as road rumble, axle noise and tire distrubances - Apps suggested more careful gear and tire manufacture and the use of more acoustical material, such as rubber, in construction of cars."

4. "Truck Noise," Noise Abatement News Letter, October 1954, p. 45, National Noise Abatement Council, New York. — "The Automobile Manufacturers Association has recommended to all truck makers the adoption of an industry standard for muffler design, which would apply to original equipment and replacement units. It would establish a permissible noise level and an agreed method of measuring exhaust noise, using the Beranek-Armour Equivalent Tone Method for measuring sound. The AMA asserts that the standard measurement method would stimulate progress in reducing noise. The Truck Noise Subcommittee of AMA, which recommended the standard, has prepared a booklet which explains evaluation of truck noise by the Beranek-Armour Method and includes a description of the required equipment and recommended operating equipment. It has been supplied to all truck manufacturers." (See below References (5) and (9).) Other items of interest are contained in this news letter:

"England Noise Concious . . . is just as alert to industrial noise control as we are here in the United States. . . ."

"Suit Instituted Against Low Flying Airplanes . . . demanding (they) be halted because they interfere unlawfully with property rights and deprive residents of the comfort, convenience and quiet to which they are entitled. . . ."

"Railroad Noise Cited . . . of trains going through the city and railroad officials have instructed trainmen to keep whistle and horn blowing at a minimum while in city limits. They also promised to do something about smoke . . . the noise problem is aggravated . . . (by the numerous grade crossings)."

"National and International. Needless noise, particularly in cities, is receiving much . . . attention . . . ordinances against unnecessary blowing of automobile horns . . . enforced (by police) . . . department . . . alert to those who distrub the peace by being excessively and needlessly noisy."

5. "Fifth Annual National Noise Abatement Symposium" at Armour Research Foundation of Illinois Institute of Technology, October 22, 1954. Vehicle Noise Session: (See Selected Reading Reference (14, 15, 16). "Quieter Automotive Vehicles," David C. Apps, General Motors Proving Grounds, Milford, Mich. "Truck Noise Abatement," Lewis Kibbee, American Trucking Associations, Washington, D. C.

6. "Trees and Shrubs Cut Street Noise," The Washington Post and Times Herald, June 6, 1954. (See Selected Reference (13) also.)

7. "The Truck Noise Reduction Program of American Trucking Associations, Inc.," Lewis C. Kibbee, Chief, Equipment and Operations Section, ATA, Inc., Washington, D.C. Address before Kiwanis Club of Akron, Ohio. April 22, 1954. 11 p. mimeo. —

This is a good background record and history of progress leading to the adoption of the industry standard for muffler design by truck manufacturers (4). Mr. Kibbee discussed also "some widespread misconceptions concerning truck noise, such as muffler cutouts which he has never seen on (any) truck." He summed up the whole philosophy of approach to the truck noise problem by saying that "the quiet muffler program will be a process of evolution and not revolution. . . . As time goes on the standard will be tightened up and commercial vehicles will get quieter and quieter . . . ."

8. SAE Journal, V. 62, No. 4, April 1954. "Industry Hushing Exhaust Noise to Meet Regulatory Demands for Quiet Trucks," pp. 17-21. (Article based on four papers and discussion of them presented at SAE National Transportation Meeting, Chicago, Nov. 1953.) "Measuring Truck Exhaust Noise," D. B. Callaway. (Microphone 50 ft. from road picks up noise as truck climbs 5 percent grade. Hood over mike prevents wind interference. Test location free of buildings, reflective banks, and off-road noise sources. Noise recorded on tape-recorder.) (See Selected References (7 and 8).)

9. AMA Truck Noise Subcommittee, David C. Apps, Chairman, Jan. 6, 1954. 4 p. "Beranek-Armour-ATA Method for the Evaluation of Truck Exhaust Noise." — The information in this reference is equivalent to a specification covering the specialized techniques for measuring and evaluating truck noise. It gives a brief outline of equipment required, procedures for vehicle operation, microphone location, recorder operation, laboratory procedure, etc. This is a most useful reference for the engineer interested in setting up field tests for measuring the effectiveness of barrier and buffer types of structures and foliage, and combinations of each, in order to evaluate the various methods of abating noise on and along highways. In general, good instrument practices are to be followed and should be adapted to the needs of the field test set up.

10. "Noise Measurements on Expressway Type Facilities," Research Report No. 15 and Appendix Report No. 15-A, Finch and Partridge, Institute of Transportation and Traffic Engineering, University of California, February 1954. — From Highway Research Abstracts, October 1954, Volume 24, No. 9, p. 15. "Noise Measurements on Expressway Type Facilities," D. M. Finch and W. A. Partridge. — "Acceleration after a stop creates the highest vehicle-noise levels on highways - more, for instance, than large volumes of traffic moving at high speed, or even up a grade.

"The authors collected data at 15 test locations ranging from a site near Vallejo in central California south to the Los Angeles area. Locations were of five types: inclined, intersection, level, elevated, and cut. Noise measurements were taken at 50, 150, and 300 feet from the centerline of the nearest traffic lane.

"In addition to the matter of acceleration, it was found that: (1) automobiles are a less-significant source of noise than trucks; (2) at close distances there is little or no difference between noise coming from cut or level freeway sections; and (3) the noise field is non-uniform near an elevated freeway section. At 50 feet noise levels were lower for the elevated than for the other test sections, but at 300 feet they were higher."

These reported tests were on open sections of highway free of barrier structures or buffer-plantings. These findings are in substantial agreement with those reported by Armour Research Foundation in its Report No. 1 for the Cook County Highway Department, Chicago, Ill. (See First Report, Selected Reference (8).) The noises were measured and compared in these two studies, but it was not expected that a solution would be found for these difficulties, within the scope of these studies. Field tests of methods of abating traffic noise on highways are needed to point up possible solutions in forthcoming programs.

11. "Apparatus for Noise Measurement," Leo L. Beranek. Form 772-A, 10 pp. illus. Acoustics Laboratory, Massachusetts Institute of Technology and Consultant in Acoustics, General Radio Company, Cambridge 39, Mass.

12. "Handbook of Noise Measurement." General Radio Company, Cambridge 39, Mass. References (11) and (12) are standard publications covering the details of techniques for measuring noise. Figures illustrate basic sound-measuring instruments, with various accessories commonly used in acoustics measurements. These two booklets furnish necessary background to the engineer interested in setting up field tests similar to those of April 30, 1952, of January 6, 1954, and of February, 1954, an outline comparison of which is presented in Table 2 of this Second Report on abating noise.

Part 2
Preliminary Report on Reduction of Fumes with Special Reference to Roadside Design

● TRAFFIC fumes are a definite menace to public health. The problem of keeping such fumes to safe levels is becoming increasingly difficult, as more and more motor vehicles crowd our highways and streets. It has been attempted in this part of the 1954 study to discuss briefly the harmful substances in traffic fumes, how they affect the individual, under what conditions they are likely to be most harmful, and what may be done to make them less dangerous.

TOXIC GASES AND SUBSTANCES ASSOCIATED WITH INTERNAL-COMBUSTION ENGINES

There are several harmful or toxic substances associated with internal-combustion engines, manely: carbon monoxide, acrylic aldehydes, benzol, and lead. Of these, carbon monoxide is by far the most common. Carbon dioxide, although a major product of combustion, is not toxic, and has not been considered in this report.

DISCUSSION OF CARBON MONOXIDE

Carbon monoxide is odorless, colorless, and tasteless, and cannot be detected by any of the senses. It is deadly because it replaces oxygen in the blood. When carbon monoxide and air are breathed into the lungs, instead of the hemoglobin combining with

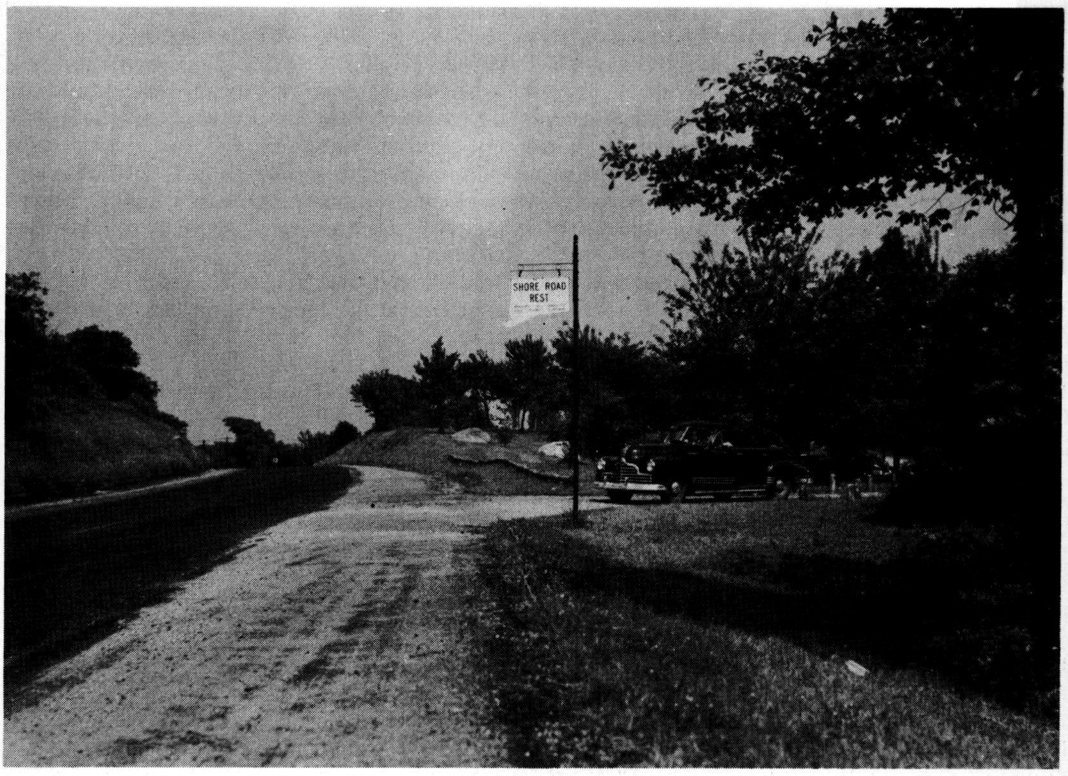

Figure 3. More parking turnouts and rest areas are nedded along heavily traveled highways where motorists may relax, breathe fresh air, and ventilate their cars. Drivers welcome the chance to get away from traffic fumes and rest their eyes. This is an entrance to Shore Road Rest in Connecticut.

Figure 4. A family enjoying the peace and quiet of the same area as Figure 3.

oxygen as it normally does, it combines with carbon monoxide. If the concentration of carbon monoxide is great enough and the time of exposure sufficiently long, death will result.

No one is entirely immune from carbon monoxide but some are much more susceptible to it than others. In general, the very young and the old are most susceptible. Small people are more susceptible than large prople. People with respiratory, thyroid, and heart diseases are particularly affected and should avoid exposure to it.

In some individuals, the body can adjust somewhat to the effects of carbon monoxide by throwing large numbers of red cells into the blood. These individuals can withstand higher concentrations than persons whose bodies have this ability to a lesser degree.

Repeated exposures to carbon monoxide, particularly to high concentrations, generally result in increasing susceptibility and may cause cumulative tissue damage. It behooves everyone to avoid exposure to traffic fumes as much as possible.

Dangerous concentrations of carbon monoxide may be present in motor vehicles on open highways in both light and heavy traffic, in congested city streets, in exclosed places such as garages, bus terminals, and the like. This gas may on occasion, be drawn into office buildings and business places through ventilating systems and open windows.

In California, more than 1,000 vehicles were tested for carbon monoxide after they had been driven over an open highway for five minutes or more. Two percent of the vehicles were found to contain dangerous concentrations that could seriously affect the behavior of drivers. One surprising fact brought out was that vehicles with one or more open windows were generally found to have higher concentrations than vehicles with closed windows. This is contrary to the general belief that open windows are a safeguard against dangerous traffic fumes.

It should be mentioned that exposure to relatively low concentrations of carbon monoxide for long periods, may be as dangerous as exposure to higher concentrations for shorter periods. Temperature and humidity also have a decided influence on the effect of carbon monoxide. Concentrations that would normally be harmless may be dangerous on days of high temperature and high humidity. The American Standards Association considers maximal permissible concentrations as 100 parts per million for periods not exceeding eight hours and 400 parts per million for periods not exceeding one hour, at 25 deg. C and 760 mm Hg. (7)

OTHER TOXIC SUBSTANCES

Acrylic aldehydes are often present in exhaust gases, particularly from engines in poor condition. They are formed by the heating and partial oxidation of oil. They cause a burning sensation to the eyes and nose. Cases have been reported where permanent damage has been caused to the eyes.

Lead and benzol are poisonous substances that are present in many gasolines. It has not as yet been determined what effect they have on the health of human beings at the concentrations found in exhaust fumes.

Freon should be mentioned here although it has nothing to do with exhaust gases. Freon is a refrigerant used in air conditioning systems of automobiles. When exposed to flame, it is converted into phosgene, one of the deadliest of gases known. Ordinarily freon is not exposed to flame, but in an accident, if the tanks holding the refrigerant were punctured and fire were present, results would be disastrous.

CONDITIONS UNDER WHICH TRAFFIC FUMES MAY ENTER MOTOR VEHICLES

1. Faulty exhaust system allowing fumes to escape under the vehicle and seep into it.
2. Fumes coming out of breather pipe from engine in worn condition and seeping into the vehicle.
3. Fumes from car ahead being drawn into ventilating system. This may happen when ventilators are open when driving too close to the car ahead in both light and heavy traffic, and when parking close behind other cars that have motors running.
4. Using the ram-jet type of defroster in which air is drawn in through ventilators.
5. Too short a tail pipe and damage to end of tail pipe causing exhaust fumes to move along with car and possibly seep into it.
6. Vehicles with flat backs such as ranch wagons and trucks with certain body types

Figure 5. A rest area in Ohio.

Figure 6. A parking turnout at a scenic overlook in historic Virginia. Note the separation of the parking area from the traveled way.

have a greater vacuum drag which may pull exhaust fumes forward so that they may enter the vehicle through open windows and ventilators.

THE EFFECT OF TRAFFIC FUMES IN CAUSING ACCIDENTS

It is not known to what degree traffic fumes contribute to highway accidents. It is known that drivers who are exposed to these fumes may have impaired judgment, slower reflexes, and may even be sufficiently overcome so that they are unable to properly control their cars. It is not unreasonable to presume that exposure to traffic fumes could have been a contributing factor in some of the accidents that are otherwise unexplained.

SUGGESTIONS FOR REDUCING THE DANGERS OF TRAFFIC FUMES[2]

1. Periodically inspect exhaust, ignition, and carburetion systems. An engine burning a proper mixture produces very little carbon monoxide.
2. Make sure tail pipe is undamaged and that it extends beyond the bumper.
3. Keep engines in good repair.
4. Keep 60 feet or more back of preceding vehicle on highways.
5. Close ventilating systems in dense, slow-moving traffic and particularly when standing, as at traffic lights.
6. Keep out of unventilated garages or garages that are not equipped to pipe away exhaust fumes from running motors.
7. Be particularly cautious on hot humid days.
8. Equip motor vehicles with carbon monoxide detectors. Such instruments that safeguard human lives would seem as important as any now furnished as standard equipment.

HOW CAN ROADSIDE DESIGN HELP TO LESSEN THE DANGER CF TRAFFIC FUMES?

There appears to be two methods: (1) Keep dense plantings well back from the traveled way so that exhaust fumes will be more readily dissipated. Distance from pavement as recommended for buffer planting in the 1953 study (first report) should be

[2] Varied recommendations made in cited references.

Figure 7. There is less annoyance from passing traffic where motels are set well back from the highway.

satisfactory. (2) Provide more parking turnouts and rest areas off heavily-traveled highways where motorists may relax, breathe fresh air, and ventilate their cars.

CONCLUSION

It has been attempted in this report to highlight some of the pertinent facts related to traffic fumes; what they are, where they may be in dangerous concentrations, how they affect people, and what may be done to reduce them to safer levels. Carbon monoxide is discussed in much greater detail in the references on traffic fumes.

REFERENCES ON TRAFFIC FUMES

1. "Vermont State Police Check Cars for Carbon Monoxide Concentrations," The Police Chief, January 1954, p. 29. — Describes findings of Vermont State Police after checking cars on bitter cold days when windows were closed and heaters were operating at full capacity.

2. White, Andrew J., "Carbon Monoxide," Copyright 1952. — This pamphlet of 35 pages discusses carbon monoxide very thoroughly, as well as other toxic substances related to motor vehicles. Ways and means to reduce toxic fumes are suggested.

3. "Governmental News," October 1952, p. 32. — This article describes an automatic system installed in New York City's omnibus garage. An alarm sounds when concentration of carbon monoxide reaches a certain level.

4. "C O Rings the Bell in Cincinnati," Public Safety, January 1952, p. 7. — This article describes the automatic system at the Motor Vehicle Testing Lanes, Cincinnati, Ohio. When the concentration of carbon monoxide reaches a certain level, red lights flash, claxons sound, overhead doors open and exhaust fans speed up.

5. Lindsley, Charles H. and Yoe, John H., "Acidimetric Method for Determination of Carbon Monoxide in Air," Analytical Chemistry, April 1949, pp. 513-515. — Description of method used in determining low concentrations of carbon monoxide.

6. "Carbon-Monoxide Detector," Compressed Air Magazine, June 1947, p. 156. —

Describes a small inexpensive device about the size of a pencil that an inexperienced person can use.

7. "Carbon Monoxide: Its Toxicity and Potential Dangers," Reprint No. 2242 from Public Health Report. (1941) — This report defines maximal permissible concentrations of carbon monoxide and discusses the subject generally.

8. California Highway Patrol - "Carbon Monoxide Survey," Reprinted, September 1939. — This report describes findings in testing more than 1,000 vehicles. Gives valuable information on effect of carbon monoxide on behavior of drivers and discusses carbon monoxide in general. A bibliography is included.

9. "Ventilation of Vehicular Tunnels," Report of U.S. Bureau of Mines to New York State Bridge and Tunnel Commission and New Jersey Interstate Bridge and Tunnel Commission - Fieldner, A.C., Henderson, Y., Paul, J.W., Sayers, R.R., and others. Reprinted New York, February 1927, from Journal of American Society of Heating and Ventilating Engineers, January-December 1926.

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