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EFFECTIVENESS OF TREES AND VEGETATION IN REDUCING HIGHWAY NOISE

— A LITERATURE REVIEW —

by

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SUMMARY

This report is a literature review of the research which has been conducted on the noise attenuating values of trees and associated vegetation, and related environmental effects. A chronology of this research, including the latest research findings, are presented along with the necessary planting criteria needed to achieve tree belt noise reduction values based on these research findings.

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PURPOSE

This literature survey was conducted to compile the research that has been done on the noise reducing effects of trees and vegetation, and to determine the practicality and efficacy of using such plantings to reduce highway generated noise.

BACKGROUND

If one is to understand the accoustical aspects of tree belts, he must understand the following concepts:

1. Tree belts must be closely planted and have sufficient depth before they can produce any significant noise reducing effects. One or two rows of trees will cause no appreciable noise reduction. They may, however, provide a slight psychological benefit by visually screening a highway from a noise sensitive area.(1)

2. The noise attenuation properties of tree belts are dependent on tree spacing, height, depth, and foliage density. But these parameters are difficult to precisely quantify. However, optimal planting (to be explained later) can result in worthwhile noise reduction.

3. Meteorological conditions such as temperature, humidity, and wind can cause variable noise reduction levels with distance.(2) However, for most distances relating to significant highway noise (highway noise is usually not a problem beyond 600 ft.(3)), these meteorological factors are not crucial.

   For atmospheric effects on general sound propagation with distance, the following summary is given:

   > "There are atmospheric effects which would seldom increase but could significantly decrease sound levels at large distances from a source. These decreases are

usually of an intermittent, short time duration and they are usually beneficial to the receiver (in giving temporary noise reduction) when they occur, but it is best not to rely on them for long-time benefits in terms of noise control design. Because some amount of wind and thermal gradients are almost always present, a small token amount of attenuation of sound is suggested for long distance sound transmission. This is assigned a value of 1 dBA* per 1,000 ft. starting after the first 1,000 ft."(4)

No precise quantitative data could be found which present the modifying effect of tree belts on such meteorological variables and corresponding sound level fluctuations. Most of the vegetative noise reduction research was conducted under good weather conditions, with wind speeds less than 10 mph to reduce this potential source of error. For wind speeds greater than 10 mph, the following excerpt is cited:

"Observations indicate that the need for downwind placement of noise screens is greater than for upwind placement, because sound levels tend to decrease more rapidly upwind anyway. Further indications are that tree barriers tend to modify the wind patterns in a way which does not favor upwind sound reduction but does favor downwind reduction. Upwind placement is therefore less efficient than downwind placement."(5)

4. Ground surfaces absorb sound, but this parameter is difficult to precisely quantify, because the attenuation rates of different soils and ground cover can be appreciably different.

Though there are some other parameters, these are the most important concepts which must be considered for an accurate appraisal of roadside tree belt noise attentuation values.

MAJOR RESEARCH STUDIES

The following is a general chronological summary of the main research and the diverse opinion concerning vegetative (trees and associated vegetation) noise reduction.

The earliest important study on the noise reducing effects of vegetation was conducted by Eyring in 1946.(6) In this classic study, Eyring, working in five varying densities of jungle vegetation, found:

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*Author's Comment: Recent noise studies use dB and dBA interchangeably when referring to dBA sound levels.

(1) A monotonical (unvarying, equal) noise attenuation with increasing frequency.

(2) A direct correlation between visibility and sound reduction.

(3) Attenuation rates from approximately 1 dB/100 ft. for sparsely vegetated areas (visibility $\approx$ 300 ft.) to $>$20 dB/100 ft. for dense jungle (visibility $\approx$ 20 ft.).

About the same time, Brückmayer measured the decrease in traffic noise produced by a row of leafy trees and forest gardens and found a 2 to 6 dB decrease in traffic noise depending on the height of the receptor.[7]

Ingard, in 1951, on the basis of theory predicted an excess sound attenuation* caused by vegetation of 6 dB per doubling of distance.[8] Also in the early 1950's, Knudson and Harris stated that trees and shrubs reduced noise levels by absorption and reflection, with density, height, and thickness of the vegetation being the independent parameters.[9]

The three most significant tree-vegetative noise studies made through the early 1960's were:

1. Jungle Acoustics — Eyring[10]

2. Experimental Study of the Propagation of Sound over Ground — Wiener and Keast[11]

3. Sound Propagation in Homogeneous Deciduous and Evergreen Woods — Embleton[12]

These researchers all found that extensive plantings of trees and similar vegetation did appreciably reduce noise, but their noise attenuation values needed to be better correlated.

Aylor, in an introduction to his own recent paper on noise research, summarized the differences between these three studies:

> "Embleton found that vegetation reduced sound equally for all frequencies between 200 - 2000 Hz while both Eyring and Wiener and Keast reported attenuation that increased monotonically with frequency. Eyring found a positive correlation between visibility and attenuation, while Embleton did

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*Author's Comment: Excess attenuation is the noise reduction level due to trees and associated vegetation in excess of normal attenuation due to distance, atmospheric effects, ground absorption, etc.

> not. Wiener and Keast's results were qualitatively similar to Eyring's, even though the plants were more similar to those studied by Embleton."[13]

Aylor suggests that some of the differences between these research results were produced by significantly different ground surfaces that caused different total attenuation rates. Aylor also discounted Eyring's comparison of visibility as a criterion for a tree stands' attenuating capacity.

Based on his own research, Aylor found that different species of trees (i.e. deciduous vs. evergreens) with significantly different visibilities had similar attenuation values. Aylor maintains that the low visibility produced by parts of deciduous trees, such as twigs and small branches, do little to attenuate noise compared to a less dense but equally noise attenuating stand of evergreens.[14]

These generally basic differences concerning the relative magnitude of the different noise reducing aspects of tree belts described by most of these researchers have made it difficult up until now to derive consistent attenuation rates.

Consequently, most of the literature revealed a wide range of thought on the effectiveness of tree belt plantings. For example, the most negative opinion is given by Beaton and Bourget.[15]

> "This topic should be laid to rest. The simple truth is that plantings possess none of the physical properties required of a good sound shield. ... (Such) noise benefits are mostly folklore."

Smith, in a recent literature review on trees and noise, concluded that a forest from 400 to 1,900 feet wide would be needed to reduce a community noise level by 25 dB, depending on which research he evaluated.[16] While such opinion is reasonably correct, current research has begun to find consistent, realistic attenuation rates for practical widths and densities of tree belts. Two main segments of this research are the studies which have recently been conducted by Aylor,[17,18] of the Connecticut Agricultural Experiment Station, and Cook and Van Haverbeke of the University of Nebraska and the U. S. Forest Service,[19] respectively.

Aylor, whose research has been previously mentioned, transmitted both random and single frequency noise through a variety of trees and vegetation and over different ground surfaces. From these studies, he found minimum excess attenuation rates of 5 - 10 dB per 100 feet of vegetation, especially for high frequency sound ($\geq$ 1,000 Hz), at which frequency range sound wave scattering by the vegetation was enhanced. In addition, he found that ground surface attenuation can produce significant attenuation rates (5 - 6 dB) per 100 feet of vegetation and ground. Such attenuation is applicable for moderately low frequency sound (200 - 400 Hz), at which frequency range ground impedance has its maximum effect.[20]

The Cook and Van Haverbeke study found attenuation rates similar to those of Aylor. However, because of their greater, direct applicability to highway noise

reduction by vegetation, the main recommendations of the Cook and Van Haverbeke research are given in the concluding section of this report.

The following general design values concerning the use of tree belts are given in the major noise abatement design texts and federal noise standards.

> "A design value of about 5 dB (A) per 100 feet of planting may be used if the trees are at least 15 feet tall and they are sufficiently dense that no visual path between them and the highway exists."[21, 22]

In one of the FHWA approved noise prediction computer models, NCHRP 117,[23] a similar design value is given along with a dBA reduction maximum for a dense stand of trees. The rationale for these design values is explained in a text prepared by the acoustical consulting firm of Bolt Beranek and Newman, Inc. for the Federal Highway Administration to aid state highway planners in utilizing the previously mentioned computer model. Their report states as follows:

> "Heavy dense growths of woods provide a small but useful amount of attenuation. NCHRP Report 117 suggests the use of 5 dBA attenuation for a 100-ft. depth of woods of sufficient density that no visual path exists through this 100-ft. depth. The woods should extend at least 15 ft. above any line-of-sight between highway traffic sources and all portions of the neighboring buildings to be protected. For an additional depth of woods of 100 ft. or more, an additional 5 dBA attenuation can be assumed, but the total attenuation claimed for all such plantings should not exceed 10 dBA in any configuration. To be effective in both winter and summer, there should be a reasonable mixture of both deciduous and evergreen trees. Also, the underbrush or ground cover should be sufficiently dense and tall to provide attenuation of sound passing under the tree growth.
>
> "For low-density growth, a token amount of attenuation, such as 2 or 3 dBA per 100 ft. depth, might be permissible, but this is left to the judgement of the user. Again, the total attenuation for such plantings should not exceed 10 dBA. The reason for imposing the 10 dBA limitation on any type of natural growth is that some sound paths are passing over the top of the trees and are frequently scattered or bent back down to earth beyond the tree growth by various mixtures of wind and temperature gradients or wind turbulence. These paths of sound (sky waves) will limit the total sound reduction that can be achieved by trees or other tall, dense natural growth at the earth's surface.
>
> "Occasional trees and hedges have aesthetic and psychological value as partial visual barriers of highway activity, but they provide negligible attenuation of sound. Do not destroy them, but do not expect them to have significant acoustic value.

"Extensive fields of tall crops, such as corn, cane, and wheat, and tall grass, weeds or other ground cover, and even freshly plowed fields can provide sound absorption for sound paths at grazing incidence (parallel to the earth's surface, passing just along the top of these absorptive surfaces). However, this is not entirely reliable as a permanent attenuator for the same reason as given above for trees; sound passing above the grazing incidence paths and returning to earth or arriving at the receiver by scattered or bent sound waves does not receive the full attenuation effects of the absorptive surface. During calm, stable atmospheric conditions, absorption effects of ground surface and vegetation can be experienced and measured and found to be significant; but during the lifetime of a highway, such ideal conditions are a rarity, and more often the flanking paths of the sky waves of sound will control. Thus, no acoustic credit should be given for this type of plant growth."(24)

CONCLUSIONS

As stated before, the objective of this literature survey was to present a summary of the most significant research conducted on the noise attenuating effects of trees and vegetation as it relates to reduction of highway noise.

Based on this available literature, it appears that the Cook and Van Haverbeke study(25) is the most relevant research done on the highway noise attenuation values of roadside tree belts. The report on their study analyzes this area of highway noise reduction methodology in realistic perspective to the physical phenomena and practical limitations involved. In so doing, it utilizes the main concepts studied in earlier research (i.e. tree spacing, ground attenuation, etc.) in presenting the most complete research found in this literature search.

The following is a summary of the Cook and Van Haverbeke research, followed with a more detailed synopsis of the results and recommendations based on this research.

SUMMARY OF RESULTS OF COOK AND VAN HAVERBEKE STUDY

Dense tree belts of varying widths, heights, and species originally planted as wind breaks were used for the study. Prerecorded highway truck noise, arterial passenger car noise, and city bus stop noise were projected through these tree belts to find the attenuation rates. (For this summary, the bus noise attenuation rates have been omitted.)

Cook and Van Haverbeke's research findings center on four main areas directly applicable to highway noise reduction by trees and vegetation:

1. Sound levels behind tree belts at various distances from the noise source.

2. Comparison of attenuation values of hard surface vs. tree-shrub-grass combinations.

3. Proper placement of the tree belt in relation to the noise source.

4. Limitations of tree belts for highway noise reduction.

Figures 1 and 2 show the results of two typical tests of recorded truck and auto noise projected through two different tree belts. The noise source for each of these tests was placed fifty feet in front of the tree belt.

1. Curve A, in each graph, is a theoretical point source sound projection curve for sound attenuation over a flat, unobstructed distance.

2. Curve B, in each graph, is a control curve of recorded truck noise projected over a surface similar to each tree belt site, but without trees, to determine how much of the attenuation was caused by the tree belt alone. Diesel truck noise was used as a control because it is the dominant highway noise.

3. Curve C (Diesel truck noise) and D (auto noise) show the attenuation rates of these recorded noises caused by the tree belt.

By comparing the control (Curve B) to the truck noise (Curve C) projected through the tree belt in each test graph, an excess attenuation of 5 - 8 dBA was found to be attributable to the trees. A 5 - 8 dBA excess reduction is significant, especially when compared to normal sound reduction with distance.

The sound reduction per doubling of flat, unobstructed distance for heavy traffic is 3 dBA, while the sound reduction for the sound of a single vehicle for the same distance nearly equals 6 dBA.[26] Therefore, without tree belts, 2 to 4 times the open space, depending on the traffic density, would be required to reduce the noise level to that caused by the tree belt.

The difference in excess attenuations between similar tree belts is probably attributable to different ground surfaces. This is shown in Figure 3, where sound attenuation is given as a function of distance and varying surface. As this graph shows, gravel attenuates more than paving, bare soil more than gravel, and so on. The ground effects are an important consideration. Quoting from the study, "It is apparent that the presence of trees, shrubs, and grass, in areas which might otherwise be hard-surfaced, would significantly reduce noise."[27]

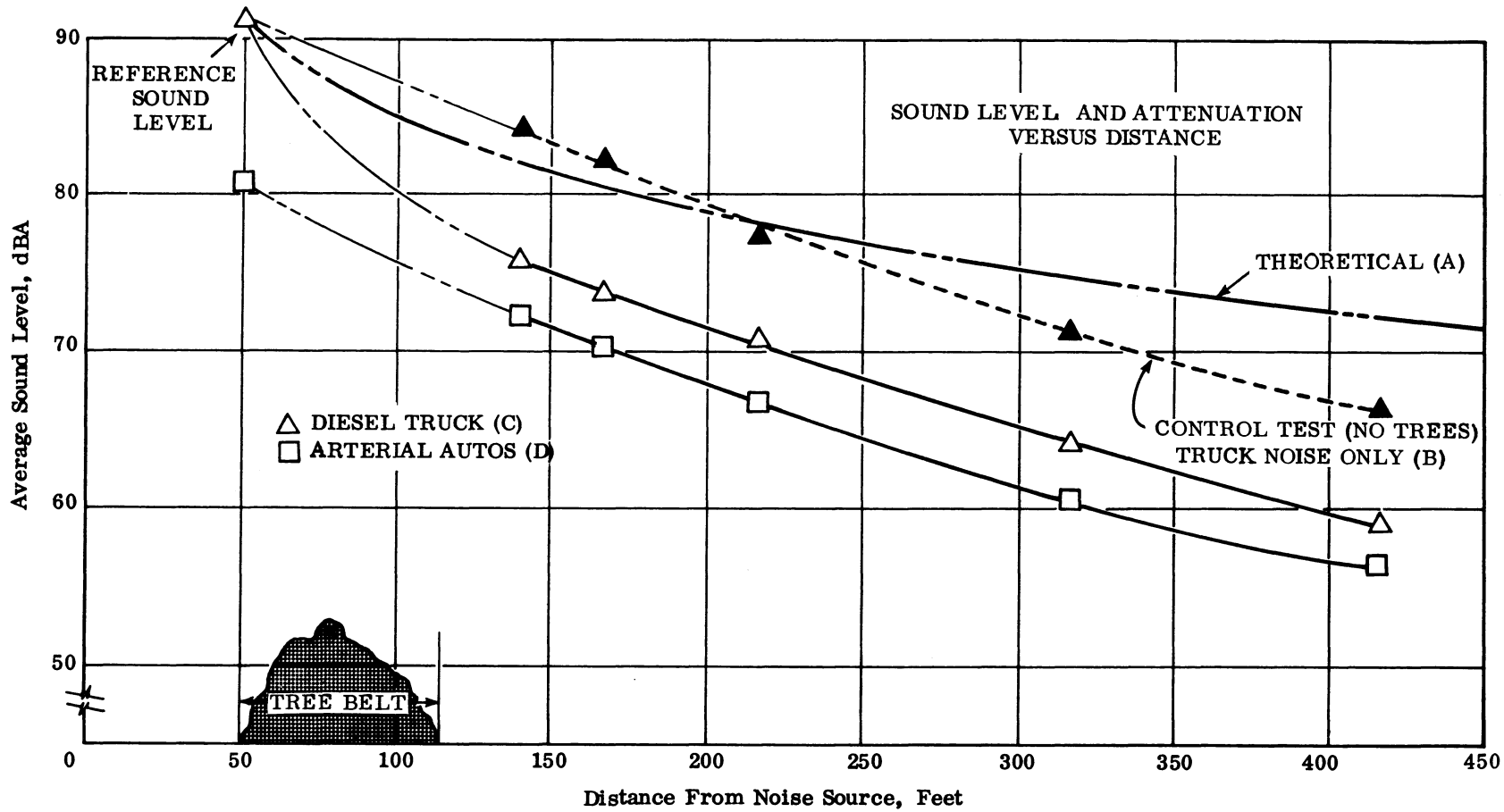

Figure 1. Noise reduction of a tree belt (from Ref. 4).

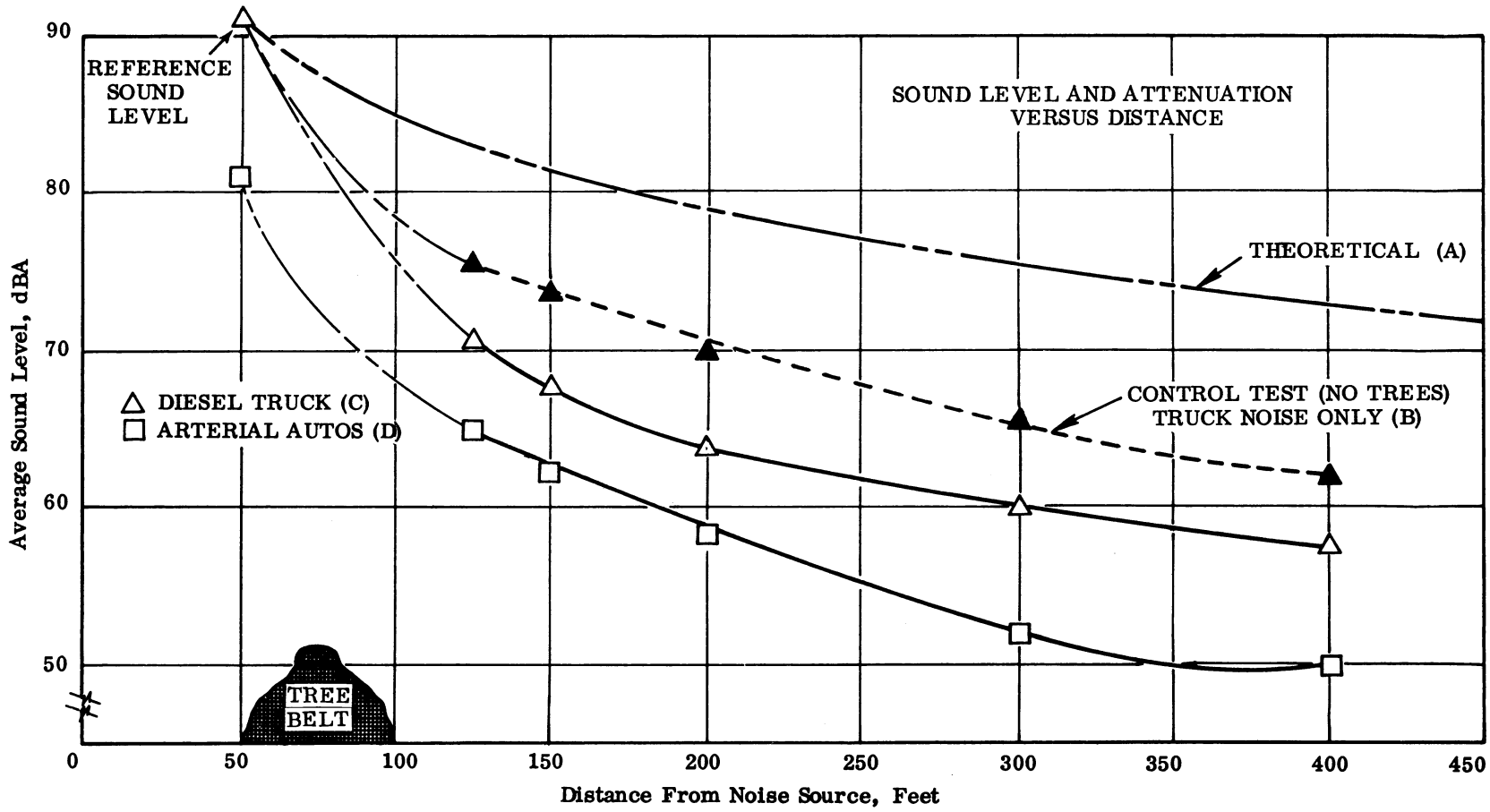

Figure 2. Noise reduction of a tree belt (from Ref. 4).

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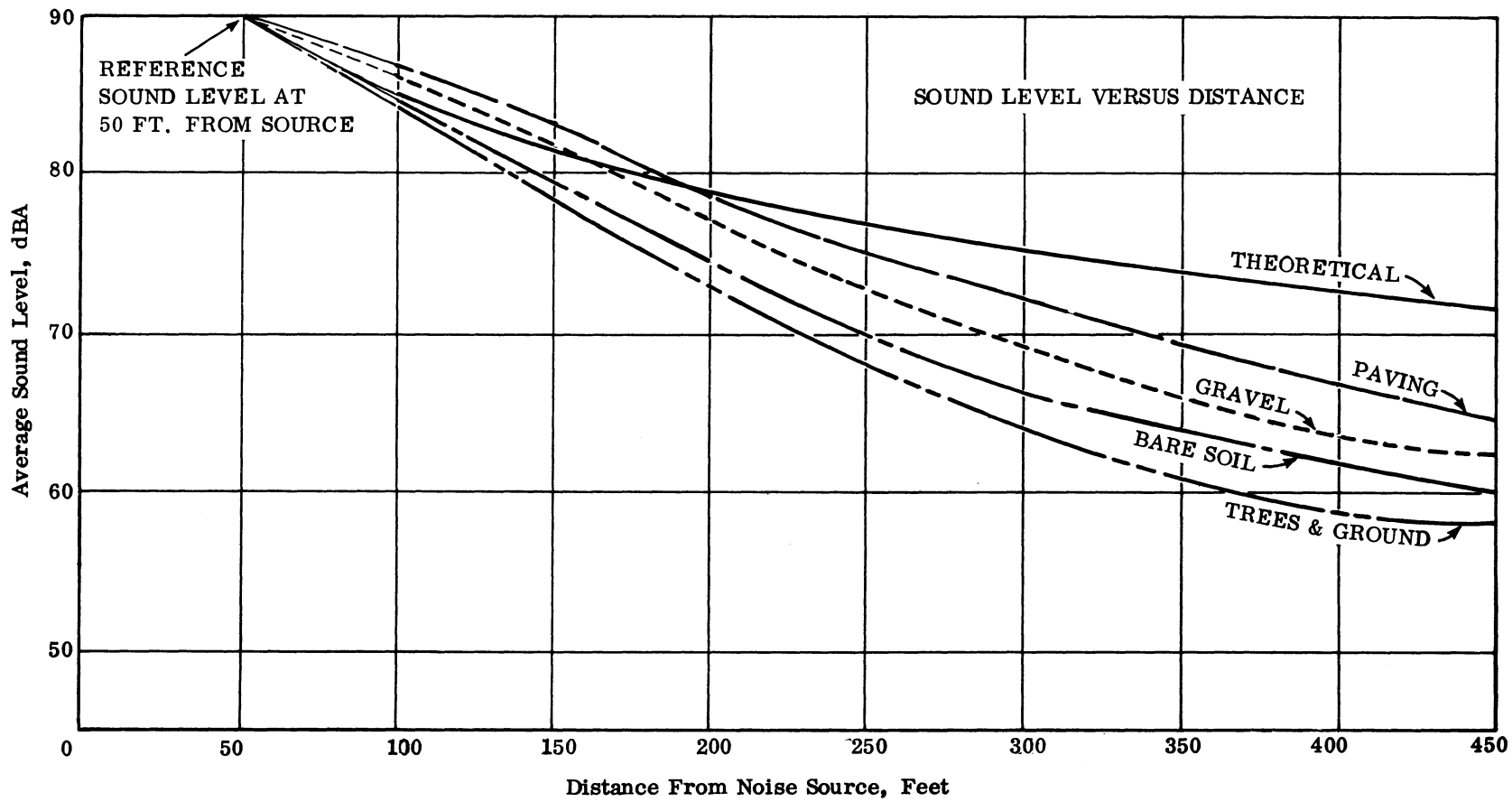

Figure 3. Sound propagation over various surfaces (from Ref. 4).

Based on the findings of this research, Cook and Van Haverbeke presented the following limitations and recommendations regarding the use of trees and shrubs as noise screens:[28]

"1. The physical nature of sound and the extreme sensitivity of the human hearing mechanism restrict the ability of trees and shrubs to reduce noise. Thus, any form of natural vegetation, no matter how extensive, is incapable of eliminating all sound; we must concern ourselves with how much or what part of a noise can be eliminated.

"2. Right-of-way or land use requirements may prevent effective noise screening.

"3. Ground forms frequently limit the use of trees as noise screens. Where traffic on elevated highways is visible over the tops of the trees for example, the sound merely passes over the trees, with relatively minor absorption from below.

"4. Natural causes also limit the effectiveness of trees in noise reduction. Very thinly planted trees, or trees in poor condition due to neglect or unfavorable growth environment, offer little resistance to the passage of sound, even though they serve as a partial visual screen.

"5. Although the limitations are formidable, trees and shrubs can effectively reduce noise levels in many applications. They are not applicable in all situations, however; a knowledge of out-of-door sound propagation, aided by experience, is necessary to make valid judgements on the use of trees and shrubs for noise reduction."

With these limitations in mind, the following recommendations from the Cook and Van Haverbeke study are presented:

"1. To reduce noise from high-speed car and truck traffic in rural areas, plant 65- to 100-foot-wide belts of trees and shrubs, with the edge of the belt within 50 to 80 feet of the center of the nearest traffic lane. Center tree rows should be at least 45 feet tall. Where right-of-way width is large, as on certain sections of Interstate highways, several rows of trees and shrubs may be planted, to reduce noise levels at adjacent property.

"2. Trees and shrubs should be planted close to the noise source, as opposed to close to the protected area, for optimum results.

"3. Where possible, use taller varieties of trees which have dense foliage and relatively uniform vertical foliage and distribution (or combinations of shorter shrubs and taller trees to give this

effect). Where the use of tall trees is restricted, use combinations of shorter shrubs and tall grass or similar soft ground cover, as opposed to paving, crushed rock or gravel surfaces.

"4. Trees and shrubs should be planted as close together as practical, to form a continuous, dense barrier. The spacing should conform to established local practices for each species.

"5. Where year-round noise screening is desired, evergreens or deciduous varieties which retain their leaves throughout most of the year, are recommended.

"6. The belt should be approximately twice as long as the distance from the noise source to the receiver and when used as a noise screen parallel to a roadway, should extend equal distances along the roadway on both sides of the protected area."

Additional experiments have recently been conducted by Cook and Van Haverbeke. In this latest research, sound level reductions were measured as a function of both vegetation and earth berms (tree-covered berms). A recent summary describing their work indicates that from preliminary results of such measurements "tree-covered landforms are considerably more effective than landforms alone or trees alone."[29]

Figure 4, which was derived from the sound level measurements of passing vehicles, compares the relative value of trees alone, bare landform alone, and combined trees and landform in reducing noise levels. A 15-ft. landform was used, with the sound projection distances being measured from the rear edge of the belt. Total transmission distances may be obtained by adding 150 ft. to the distances shown on the graph.[30]

Since recommendations based on this phase of their research are still considered tentative, the main points of this research as stated in the following summary are presented to give the reader an insight into the latest vegetative noise reduction research:

"1. To reduce noise from high-speed car and truck traffic, construct a landform of sufficient height to screen the noise source from view at the location to be protected. Plan trees, shrubs and grass on and around the landform to extend the range of protection and further reduce the noise level.

"2. To reduce noise from moderate speed auto traffic in urban areas, construct a landform or other solid barrier 6 to 8 ft. high. Plant dense shrubs in front of the barrier and taller trees behind it, to form a composite structure having a total depth of at least 20 ft. Maintain a soft surface of grass or other plant materials throughout the area, where possible, to reduce reflected noise."[31]

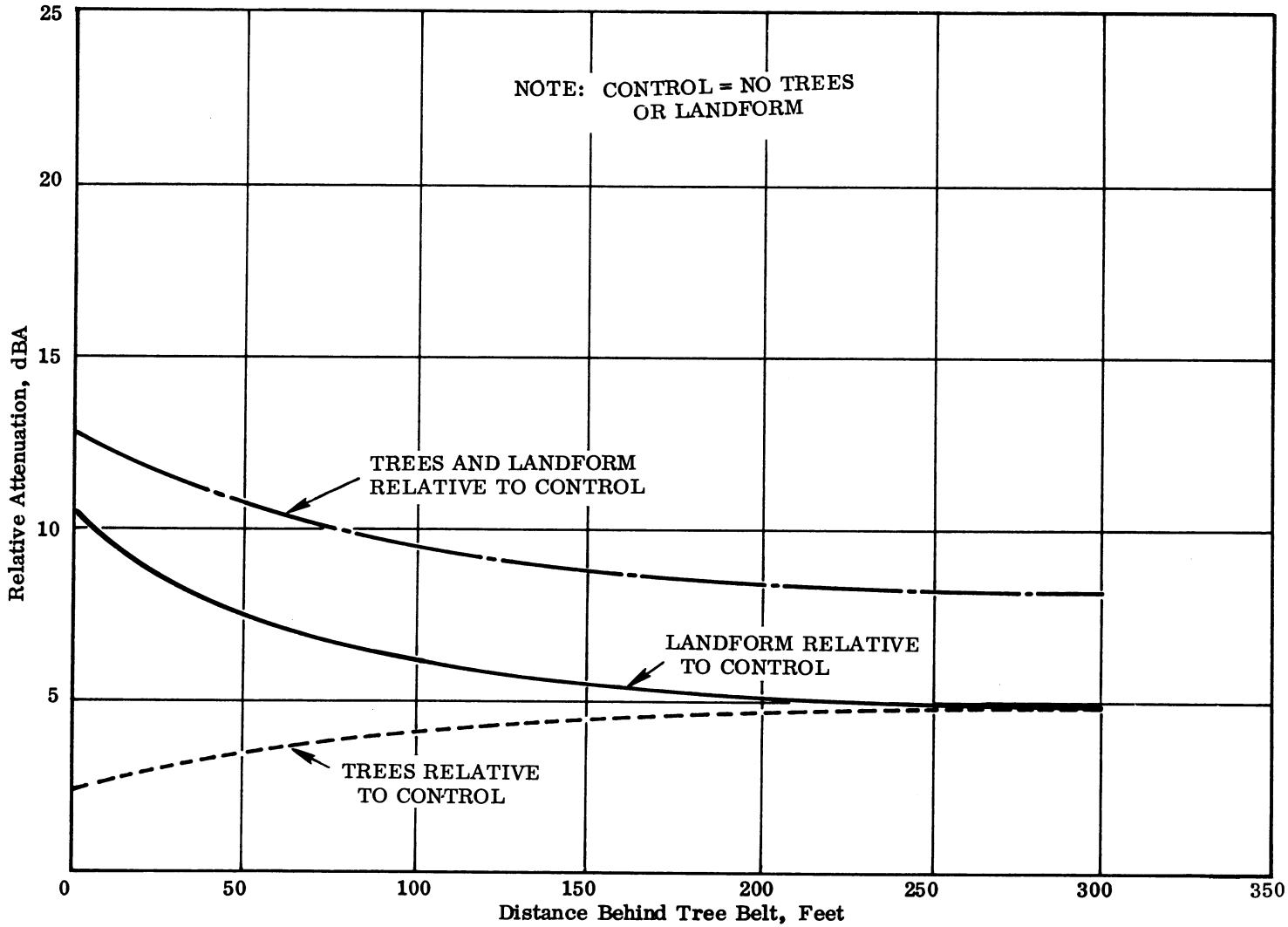

Figure 4. Relative noise reduction effectiveness of trees and land forms (from Ref. 29).

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REFERENCES CITED

1. Gordon, Colin G., et al., "Highway Noise — A Design Guide for Highway Engineers," NCHRP Report No. 117, Washington, D. C., 1971.

2. Ingard, Uno, "A Review of the Influence of Meteorological Conditions on Sound Propagation," The Journal of the Accoustical Society of America, Vol. 25, No. 3, May 1953.

3. Beaton, John L., and Louis Bourget, "Can Noise Radiation From Highways be Reduced by Design," HRR 232, Washington, D. C., 1968.

4. Bolt Beranek and Newman, Inc., Fundamentals and Abatement of Highway Traffic Noise, Cambridge, Massachusetts, no date.

5. Cook, David I., and David F. Van Haverbeke, "Trees and Shrubs for Noise Abatement," Research Bulletin 246, The Forest Service, U. S. Department of Agriculture, July 1971.

6. Eyring, Carl F., "Jungle Acoustics," The Journal of the Acoustical Society of America, Vol. 18, No. 2, October 1946.

7. Furrer, Willi, Room and Building Acoustics and Noise Abatement, Butterworths, Washington, D. C., 1964.

8. Ingard, Uno, op. cit.

9. Knudsen, Verne O., and Cyril M. Harris, Acoustical Designing in Architecture, Wiley and Son, New York, 1950.

10. Eyring, op. cit.

11. Wiener, Francis M., and David N. Keast, "Experimental Study of the Propagation of Sound over Ground," The Journal of the Acoustical Society of America, Vol. 31, No. 6, June 1959.

12. Embleton, T. F. W., "Sound Propagation in Homogeneous Deciduous and Evergreen Woods," The Journal of the Acoustical Society of America, Vol. 35, No. 8, August 1963.

13. Aylor, Donald, "Noise Reduction by Vegetation and Ground," The Journal of the Acoustical Society of America, Vol. 51, No. 1 (pt. 2), January 1972.

14. Ibid.

15. Beaton and Bourget, op. cit.

16. Smith, William H., "Technical Review — Trees in the City," American Institute of Planners Journal, Vol. 36, No. 6, 1970.

17. Aylor, op. cit.

18. Aylor, Donald, "Sound Transmission through Vegetation in Relation to Leaf Area Density, Leaf Width, and Breadth of Canopy," The Journal of the Acoustical Society of America, Vol. 51, No. 1 (pt. 2), January 1972.

19. Cook and Van Haverbeke, op. cit.

20. Aylor, Donald, "Sound Transmission".

21. Galloway, William J., Welden F. Clark, et al., "HIGHWAY NOISE — Measurement, Simulation, and Mixed Reactions," NCHRP Report No. 78, Washington, D. C., 1969.

22. _____, Proposed Policy and Procedure Memorandum (PPM) 90-2, Department of Transportation, Federal Highway Administration, Federal Register, Vol. 37, No. 114, June 13, 1972.

23. Gordon, Colin G., op. cit.

24. Bolt Beranek and Newman, op. cit.

25. Cook and Van Haverbeke, op. cit.

26. Harmelink, M. D., "Noise and Vibration Control for Transportation Systems," D.H.D. Report No. RR168, Department of Highways, Ontario, Canada, 1970.

27. Cook and Van Haverbeke, op. cit.

28. Ibid.

29. Anonymous, "Trees and Landforms Reduce Traffic Noise Pollution," Rural and Urban Roads, Vol. 11, No. 5, May 1973.

30. Ibid.

31. Ibid.