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Environmental Methods for Transport Noise Reduction

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CRC Press
Taylor & Francis Group
Boca Raton London New York

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CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

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No claim to original U.S. Government works
Version Date: 20140909

International Standard Book Number-13: 978-1-4822-8877-3 (eBook - PDF)

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10 Economic analyses of surface treatments, tree belts, green façades, barriers, and roofs 221

RONNY KLÆBOE AND KNUT VEISTEN

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Preface

Exposure to noise from roads and railways is widespread, and the problem is increasing, primarily as a consequence of the continuous urbanization and growth of the transport sector. Traffic noise causes annoyance and sleep disturbance, and it interferes with rest, concentration, speech communication, and learning. There also is increasingly strong support for a causal link between long-term exposure to road traffic noise and cardiovascular disease, including hypertension and myocardial infarction.[1]

The most effective noise-mitigation method is to reduce noise emissions at the source, for example, by means of regulations demanding quieter engines, tires, or road surfaces, or by limiting traffic flow volumes and introducing stricter speed limits. However, such methods are often difficult to implement for economic, city planning, or political reasons. Therefore, at-source noise reduction must be complemented with methods that act on the noise during its path to the receiver. The aim of this book is to encourage the use of new and environmentally friendly methods of this kind.

Environmental Methods for Transport Noise Reduction presents the main findings of the research project HOlistic and Sustainable Abatement of Noise by optimized combinations of Natural and Artificial means (HOSANNA). The project aimed to develop a toolbox for reducing road and rail traffic noise in outdoor environments by the optimal use of vegetation, soil, and other natural and recycled materials, in combination with artificial elements.

The HOSANNA project studied a number of abatement strategies that might achieve cost-effective improvements using new barrier designs; planting of trees, shrubs, or bushes; ground and road surface treatments; and greening of building facades and roofs. Vegetated areas and surfaces are greatly appreciated in both urban and rural environments. The beneficial effects of greening mean that the costs of new greening or of maintaining existing green surfaces are often easy to justify, even without considering the benefit of environmental noise reduction. The thrust of the HOSANNA project was to find better ways of using vegetated surfaces and recycled materials to reduce road and rail traffic noise and improve the perceived

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sound environment. The noise reduction was assessed in terms of sound level reductions, perceptual effects, and cost–benefit analyses.

Traffic noise situations are often complex and a single noise mitigation measure is seldom sufficient. Some of the options we discuss in this book each lead only to 2 to 3 dB(A) reduction in noise, so an appropriate combination of measures is needed to obtain a larger effect. Other individual noise abatements are expected to reduce noise by 10 dB(A) or more. It should be noted that most of the estimated noise reductions have been calculated using advanced numerical methods, rather than measured in real situations, so a nonnegligible uncertainty is expected in real situations. To minimize this uncertainty, the estimation methods have all been validated and are applied in situations that are as realistic as possible. In addition, the impairment in performance due to meteorological effects has been estimated for selected cases by modelling the effects of mean wind and turbulence.

The methods presented in this book act by exploiting various acoustic phenomena that influence sound during their paths from source to receiver. Chapter 1 (Forssén et al.) reviews the general principles of outdoor noise propagation, and specifically those phenomena that are relevant for the efficiency of the mitigation methods, which are introduced in Chapters 2 to 8.

The conventional noise control solution is to erect noise barriers, and much has been learned over the years about noise barrier design.[2] However, there is still room for new ideas, as is evident in Chapter 2 (Defrance et al.), where solutions like low-height vegetated barriers and vegetated barrier caps are discussed.

Chapter 3 (Horoshenkov et al.) presents detailed analyses of the acoustic performance of plants and soil, and illustrates how the acoustic absorption of soils can be enhanced by selecting the right type of low-growing plants. Chapter 4 (Van Renterghem et al.) presents corresponding results for hedges, trees, and tree belts, and their effect on reflection, diffraction, and scattering of sounds. Chapter 5 (Van Renterghem et al.) provides design tips for planting trees and tree belts along roads. Planting schemes may take advantage of several acoustic phenomena, such as multiple scattering in tree belts and upward refraction by trees planted close to noise barriers.

Sound travelling directly from source to receiver will interact with sound reflected from the ground, a phenomenon called *ground effect*. Chapter 6 (Attenborough et al.) suggests a new set of noise control options that uses the ground effect. Examples are the distribution of small protruding elements or grooves over the ground in such a way that the ground effect cancels sound in a frequency range that will reduce the noise from surface transport. Chapter 7 (Attenborough et al.) follows this up by discussing how different ground types give rise to different ground effects, and how this knowledge can be used to choose grounds for improved noise reduction. This chapter also includes a section on how to improve the noise-reducing potential of porous asphalt by burying resonating chambers and resonators, which act on a specific frequency region of the noise.

Chapter 8 (Kang et al.) shows how vegetation on facades and roofs can improve the acoustic environment in urban streets, squares, and courtyards, in addition to the aesthetic and ecological benefits of increasing the amount of greenery in the city. Although the acoustic effect of single measures, such as vegetation on a single facade, may be small, combined measures may lead to substantial noise reduction.

The main part of this book discusses noise reduction in terms of sound pressure levels. This gives a fair indication of the corresponding improvement of the perceived acoustic environment. However, noise mitigation also changes the frequency composition and variability of the mitigated noise at the listener location, and may influence the audibility of other sounds in the environment as well as changing visual features of the environment. Such perceptual effects of noise mitigation are discussed in Chapter 9 (Nilsson et al.). Chapter 10 (Klæboe and Veisten) takes evaluation a step farther, and presents economic analyses of noise mitigation measures, using as examples several of the measures proposed in the previous chapters. In the analyses, costs and benefits of a noise mitigation project are valuated and the project is considered cost efficient if it cost less than the total value of the benefits. These analyses show that many of the proposed methods have the potential of being cost efficient, in several cases robustly so.

Mats E. Nilsson, Jörgen Bengtsson, Ronny Klæboe (Editors), and
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On behalf of the HOSANNA project

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Glossary

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Absorbent materials Sound absorbents or absorbing materials reduce the reflection of sound as a result of being porous so that air particle motion associated with sound is able to penetrate and its energy is converted into heat by friction with the walls of the pores.

Absorption coefficient Result of measuring the sound-absorbing property of a surface, usually frequency and angle dependent. The measurement is made at normal incidence in an impedance tube or at random incidence in a reverberation chamber.

Absorption of sound The process by which sound energy is converted to heat. This can happen in the atmosphere through air absorption, nonporous boundary friction or interaction with a porous boundary.

Acoustically hard/soft A surface that reflects all of the sound that arrives at it is described as acoustically hard, whereas a surface that absorbs some or all of the sound that arrives at it is called acoustically soft.

Atmospheric turbulence Random irregular motion or fluctuation in temperature of fluid (e.g., air) induced by wind friction with the ground or by uneven surface heating. It scatters sound to an extent that increases with frequency. In the atmosphere, it reduces ground effects and the acoustical performance of barriers.

Auralisation A method of simulating a real (e.g., an outdoor) hearing experience in a laboratory or through a virtual environment.

Benefit–cost ratio The ratio between the cash value of benefits accruing from a (noise reduction) action and the costs of implementing the action.

Berm An earthen barrier or bank of earth that may be used for noise control. Frequently, berms are made from soil removed during associated construction activities and planted to improve appearance.

Damping ratio A dimensionless measure of how rapidly oscillations decay.

Diffraction The physical phenomenon by which sound bends around the edges of an obstacle, e.g., the top of a noise barrier.

Diffraction grating A regularly spaced array of obstacles to a sound wave that causes enhanced reflection or cancellation when the wavelength, spacing, and angle satisfy certain conditions.

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Diffuse A sound field at a receiver is considered to be diffuse if it contains components travelling in all directions.

Drag Drag (sometimes called *air resistance*) is a type of friction that results in forces acting opposite to the relative motion of any object moving with respect to a surrounding fluid.

Drag coefficient The drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance experienced by an object moving in a viscous fluid.

EA *See* excess attenuation.

Excess attenuation Attenuation of outdoor sound in excess of that due to wavefront spreading and, possibly, air absorption.

Flow resistivity A measure of the ease with which air can pass in and out of a porous surface. Specifically, it is given by the ratio of applied pressure gradient to resulting volume flow per unit thickness of material.

Geometric spreading The physical phenomenon by which sounds spread from a source after generation. This means that sound levels will reduce from distance alone. Spherical spreading and cylindrical spreading are special cases giving rise to 6 dB and 3 dB reduction per doubling of distance, respectively.

Ground effect The physical phenomenon (interference) through which sound reflected from the ground and travelling to a receiver along the reflection path either reinforces or cancels sound that arrives at the receiver directly.

Impedance The ratio of pressure to normal velocity at a surface.

Impedance tube A rigid tube with a loudspeaker at one end and an acoustically hard termination at the other, along which it is possible to measure the pressure profile or the complex pressure (i.e., both magnitude and phase) at two or more fixed microphone positions or continuously using a probe microphone.

Insertion loss The insertion loss due to a mitigation measure is the difference between the sound levels at a given location without and with a mitigation measure. Usually stated in decibels (dB).

Insolation Amount of sunlight incident on a surface.

Leaf area density Leaf area per unit volume (can be one-sided or two-sided).

Loudness The perceived intensity of sounds (unit: sone). Also the output of a psychoacoustic model of the perceived loudness of sounds.

Loudness level The loudness of a sound, expressed as the level of an equally loud 1-kHz tone (unit: phon). Also, the output of a psychoacoustic model of the perceived loudness of sounds.

Notice event An auditory event that is noticed by a listener in a given environment.

Open porosity Volume fraction of interconnecting pores that open to the surface of a material.

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Porosity Total fraction of a material occupied by pores including "dead end" ones.

Porous asphalt An asphalt mix of stones and binder in which a gap in the stone size distribution is deliberately created so as to result in air-filled voids.

Pressure resistance *See* flow resistivity.

Pressure resistance coefficient *See* flow resistivity.

Reflection The process by which the sound incident on a surface is directed away from the surface. During specular reflection, the sound is directed away from the surface at the same angle from the surface as that made by the incident sound. Reflection represents a special form of scattering when the scattering object is very large compared with the incident wavelength.

Reflection coefficient The fraction of incoming sound intensity that is reflected.

Refraction The process involving change of sound speed by which the direction of sound penetrating a surface or region is changed.

Resonator A structure that resonates. If an undamped structure is vibrated at the frequency of resonance (resonant frequency), the amplitude of vibration grows arbitrarily large. Typical resonators include damping and can be used to absorb sound near the resonance frequency.

Reverberant room Sometimes called a *reverberation chamber*, a room specially constructed with acoustically-hard surfaces, non-parallel walls, and aids to diffusion.

Scattering The process by which an obstacle influences incident sound. It depends on the relative size of the obstacle compared to an incident wavelength. If the obstacle is very small compared with the wavelength, its influence is small, but the combined influence of multiple scattering may be significant if there is a large number of small obstacles per unit volume.

Scattering coefficient The fraction of incoming sound power that is scattered.

Sonic crystal A regularly spaced array of (usually acoustically hard) scattering objects giving rise to stop and pass bands in acoustic transmission at frequencies that depend on the centre-to-centre spacing.

Soundscape The overall acoustic environment, including sounds from all audible sources.

Specular reflection point The position on a reflecting surface at which the angle of incidence is equal to the angle of reflection.

Substrate An underlying layer (a substratum). Material on which plants grow or are attached.

Substratum *See* substrate.

Surface wave A wave in the close vicinity of the ground surface characterized by cylindrical spreading and exponential decay with the height above the surface.

Thermal dissipation Conversion of mechanical energy to heat. Inside a pore of a porous material it accompanies heat transfer between compressions and rarefactions of the pore fluid and pore walls during the passage of a sound wave.

Tortuosity A measure of the deviation of streamline flow from a straight line through a porous material.

Transfer function The ratio of signals at two positions in a signal processing chain.

Transfer matrix approach A method of modelling sound propagation through a layered system in which the velocities or pressures at each interface are included in a matrix.

Viscous loss Conversion of mechanical energy into heat through fluid viscosity.

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The HOSANNA project

This book is based on research conducted in the research project **HO**listic and **S**ustainable **A**batement of **N**oise by optimized combinations of **N**atural and **A**rtificial means (HOSANNA). The project aimed to develop a set of tools for reducing road and rail traffic noise in outdoor environments by the optimal use of vegetation, soil, and other natural and recycled materials in combination with artificial elements.

The project studied a number of green abatement strategies that might achieve cost-effective improvements using new barrier designs; planting of trees, shrubs, or bushes; ground and road surface treatments; and greening of building facades and roofs. The noise reduction was assessed in terms of sound level reductions, perceptual effects, and cost–benefit analyses.

The project was coordinated by Chalmers University of Technology in Gothenburg, Sweden (coordinator Associate Professor Jens Forssén), and involved 13 partners from 7 countries. The research received funding from the European Union Seventh Framework Programme (FP7/2007–2013) under grant agreement no. 234306, collaborative project HOSANNA.

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