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NORD 2000. EFFECTS OF SCATTERING IN THE NEW NORDIC PREDICTION METHODS FOR ENVIRONMENTAL NOISE

S.Å. Storeheier

SINTEF Telecom and Informatics, N-7465 Trondheim, N-7465, Trondheim, Norway

Tel.: +47 73 59 26 38 / Fax: +47 73 59 43 02 / Email: svein.storeheier@informatics.sintef.no

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ABSTRACT
Simple models are developed for the prediction of scattering effects related to sound propagation above rough ground surfaces and through housing areas or forests. The theoretical background is briefly examined, and the implementation into a sound propagation model is discussed.

1 - INTRODUCTION
A new Nordic prediction method for environmental noise is in development. The propagation part of it considers the effects of ground, topography, diffraction, reflection, meteorology (to a certain extent) and scattering. The scattering effects of main interest here are related to sound propagation above uneven (rough) terrain surfaces, and sound propagation through housing areas and forests. Scattering phenomena are very complex by nature and a thorough acoustical treatment was far beyond the possibilities within the project. The scope of this work is therefore to investigate sound scattering in some detail, and suggest possible models and implementations within the frames of a practical prediction method.

2 - SCATTERING BY GROUND SURFACE ROUGHNESS
The sound propagation model deals with terrain segments in order to simplify and keep track of the calculations. The segments are approximations to the real terrain. Small- and moderate scale roughness in the ground surface is not included in this terrain description, but has to be considered as properties to the segments.

The effect of a rough ground surface was split into two cases: i) regular (small) roughness patterns (*small scale roughness*) which can lead to a change in the apparent ground impedance (at low frequencies), ii) a random roughness pattern (*moderate scale roughness*) can be transformed into a loss in the coherent part of the surface plane wave reflection coefficient, thereby altering the spherical reflection and the coherent sound propagation.

2.1 - Small scale roughness
Small scale roughness is characterised by relatively small irregularities essentially on a plain surface. The extent of the irregularities is kept below certain limits (0.5-1 m) and form groups or patterns which are characteristic of an area. The irregularities may be described as 2D- or 3D bosses. The material of the irregularities is mainly that of the base ground surface. This scattering occurs when the extent of the objects is small compared to the acoustic wavelength of interest. Effects on sound propagation from such small-scale roughness are seen which are considered of practical importance [1].

The essence of recent work in this field is that the small-scale roughness acts to modify the acoustic impedance associated with the flat surface. 2D boss scattering algorithms are developed to include the effect of periodic structures by introducing simple diffracting grating theory, [2].

The starting point for the *model* proposed here is taken from one of the basic approximate forms discussed by Attenborough [3]:

$$\beta_{\mathrm{r}} = \beta_{\mathrm{s}} - \mathrm{i}\,(\mathrm{k_o}\sigma_{\mathrm{v}}/2 + \beta_{\mathrm{s}}\ \mathrm{k_s}\sigma_{\mathrm{v}}) \quad (1)$$

where β_r is the apparent admittance of the rough surface containing the scatterers, β_s is the normalized admittance for the lower material if it were smooth, σ_v is the volume of scatterers above the plane per unit area. The wavenumber in the upper fluid is k_0 and k_s is the complex wavenumber of the lower material.
For a high flow resistivity semi-infinite and rigid-porous material, the rough surface effective admittance β_r can be further approximated by [1]):

$$\beta_r \approx \beta_s - i\,(C + Df) \tag{2}$$

where f is the frequency.
The constants C and D can be determined for simple special cases of "roughness", like hemi-spherical (3D-) or semi-cylinders (2D-) bosses. The constants depend on the size of the elements, their packing density and the base material porosity. Details are given in [4].
The model is implemented by determining the constants C and D for the actual boss approximation, calculating β_r using the known β_s and then transforming to the specific acoustic impedance Z that enters into the propagation calculation, according to: $Z = 1/\ \beta_r$.
The model is subject to the restriction $ka \leq 1$, i.e. the height (and spacing) of the bosses should be small compared to the acoustic wavelength of interest. A transition between β_r and β_s may be necessary.

2.2 - Moderate scale roughness

Moderate scale roughness is generally the (rough or uneven) terrain configuration in between small-scale roughness and larger terrain undulations which are handled by terrain segments. A characteristic feature is random height variations extending over a larger area. The effects of hilly terrain, significant large-scale terrain undulations or single scattering objects etc. are not covered.
The simple model that is proposed assumes that the surface exhibit pronounced height variations of a random nature.
The Kirchhoff approximation offers an approach which seems suitable in handling such situations, see for instance [5]. For the special case of a gaussian height variation, the coherent scattered field can be handled conceptually by introducing a modified surface reflection coefficient, see for instance [6]. The modified reflection coefficient assuming single scattering, can be written, according to Ogilvy [7]:

$$R' = R_p \exp\left(-2\,(k\sigma \sin\phi)^2\right) \tag{3}$$

R_p is the complex plane wave pressure reflection coefficient for the surface depending on the surface impedance and the grazing angle of incidence ϕ (angle relative to the horizontal), k is the wave number in air. σ is the rms-value of the surface heights, provided the distribution is gaussian. The above relation is valid for single scattering. For multiple scattering that may be more relevant for practical situations, an approximate solution is taken from [8]. The modified reflection coefficient is now:

$$R' = R_p \exp\left(0.5\ \mathrm{Fmsc}\,(X)\right) \tag{4}$$

Fmsc is a polynomial fit to the natural logarithm of the coherent multiple scattered intensity versus the Rayleigh roughness parameter X ($= k \cdot \sigma \cdot \sin\phi$), given by:

$$\mathrm{Fmsc}\,(X) \approx 1.066X - 8.\ 543X^2 + 4.710X^3 - 0.830X^4 \tag{5}$$

valid for X-values less than 2.
The simple model presented here for the effect of coherent scattering, can easily be implemented into general propagation models by replacing R_p by R' in the complex image source strength, i.e.:

$$Q = R' + (1 - R')\,F\,(\ w) \tag{6}$$

F(w) is the boundary surface loss.
The surface height rms-value is the only parameter needed. The simple relations in Eq. (3) and (4) for coherent scattering are to be regarded as first order approximations. In order to increase the accuracy it is necessary to supply a more detailed description of the surface characteristics.

3 - SCATTERING BY GROUPS OF OBSTACLES

The problem addressed was how to estimate the resulting sound attenuation during sound propagation through scattering areas like housing areas and forests, as a function of frequency. The sound propagation in these two situations will behave quite differently due to scattering, although the basic principles are the same.

3.1 - Basic models

The sound pressure level correction $C_{sc}(r)$ in dB due to scattering, at a distance r(m) for a point source is estimated to:

$$C_{sc}(r) = \Delta L(h', \alpha, r') + 20\log(r \cdot 8 \cdot nQ) \tag{7}$$

resulting from a development on the scattering model by Leschnik [9]. $\Delta L(h', \alpha, r')$ is the level correction due to scattering and spherical spreading given in this reference. h′ and r′ are values of obstacle height h and receiver distance r respectively, normalised with respect to (1/nQ). a is the absorption coefficient of the scatter object. The quantity nQ is related to the scattering process (n is the scatter density, Q is the relevant scattering cross section) and takes value specific to the scatter objects. The scattering process will interfere with the ground correction.

The level correction can now be estimated if the quantity nQ is determined. It is shown that estimates of nQ (fully developed scattering) can be expressed:

$$nQ(\text{housing}) = n' \cdot S/(4 \cdot h \cdot A) \tag{8}$$

n′ is the fraction of all buildings plan area to the total area (a number between 0-1), S is the sum of all wall and roof surfaces (m^2) of an average building, h is the height (m) of an average building, A is an average building plan area (m^2).

The frequency dependence of the scattering follows that of [10] except for minor adjustments.

$$nQ(\text{forest}) = n'' \cdot d \tag{9}$$

n'' is the density of trees (m^{-2}), d is the mean trunk diameter of the trees.

It is assumed that significant scattering is developed above the limiting frequency

$$f' = c/(\pi \cdot d) \tag{10}$$

where c is the sound speed. Above this frequency a frequency weighting function is estimated by the relative scattered intensity function for cylinders [11].

3.2 - Implementation

The scattering process interfere with the ground correction, Cg. Cg and $C_{sc}(r)$ are not additive in the usual sense.

Taking into consideration the loss of coherent sound and the increase of incoherent sound due to this kind of scattering, the combined frequency dependent level correction (in dB re free field) can be expressed approximately, following the ideas in [12]:

$$C_{g\cdot+sc} \approx 10\log\left\{(1 - kf \cdot T) \cdot abs(1 + pr)^2 + kt \cdot T\left(1 + abs(p_r)^2\right)\right\} + kf \cdot T \cdot kp \cdot C_{sc}(r) \tag{11}$$

kf is a normalised frequency weighting function taking into account the frequency dependence of the scattering in question. kf also act as the fraction of coherent sound that is transformed into incoherent sound. T is a function giving a smooth transition into scattering, also avoiding overestimation at short distances. kp is a constant of proportionality. The details can be found in [5]. p_r is the complex ground reflected sound pressure (relative to the sound pressure of the direct field) as given in standard textbook on acoustics and sound propagation, involving the acoustic surface impedance and the complex image source strength. In case of no scattering the function kf is set to zero, giving the ground correction Cg depending on p_r.

Investigations [12,13] indicate that multiple scattering plays a minor role in the actual practical situations, i.e. the scattering process is close to a sound energy extinction process. In this case the sound energy removed from the direct propagating wave causes a sound level reduction proportional to the sound path length in the scattering volume. In case of belts of scatter volumes along the propagation distance, a first order estimate is to calculate the scatter effect for a sound path corresponding to the distance within the scatter volumes only.

4 - DISCUSSION

Models are presented to estimate scattering effects related to sound propagation above rough ground surfaces, or through housing areas or forests. The models reflect simplifications and should be considered

as first order approximations. On the other side, the models have to be applicable in the sense that they should comply with the comprehensive prediction method. The number and complexity of the corresponding input data should also be considered.
The implementation of the models should not cause serious problems. The input data that is needed can be determined from practical experience. At present it remains to specify proper input data options, but this will be prepared.
A problem in model development is the validation. So far in this investigation no real field validation has been possible. Results from the small scale roughness model has been compared to results from scale model measurements. The scattering effect in housing areas and forests was compared to results found in the literature. The results from these investigations are very encouraging, but the number of cases are low.

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